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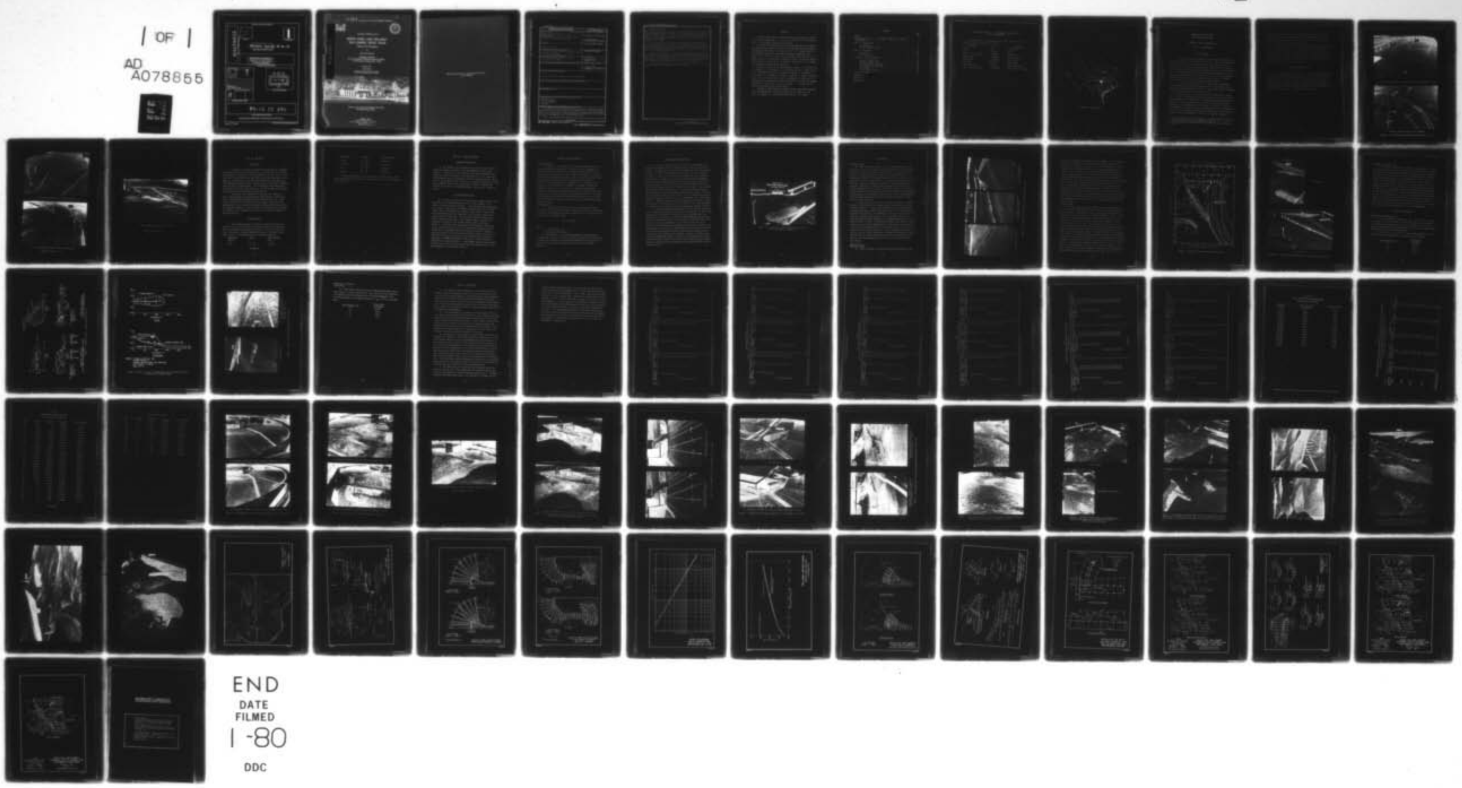

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TECHNICAL REPORT H-76-10

NORTH FORK LAKE SPILLWAY
SAN GABRIEL RIVER, TEXAS

Hydraulic Model Investigation

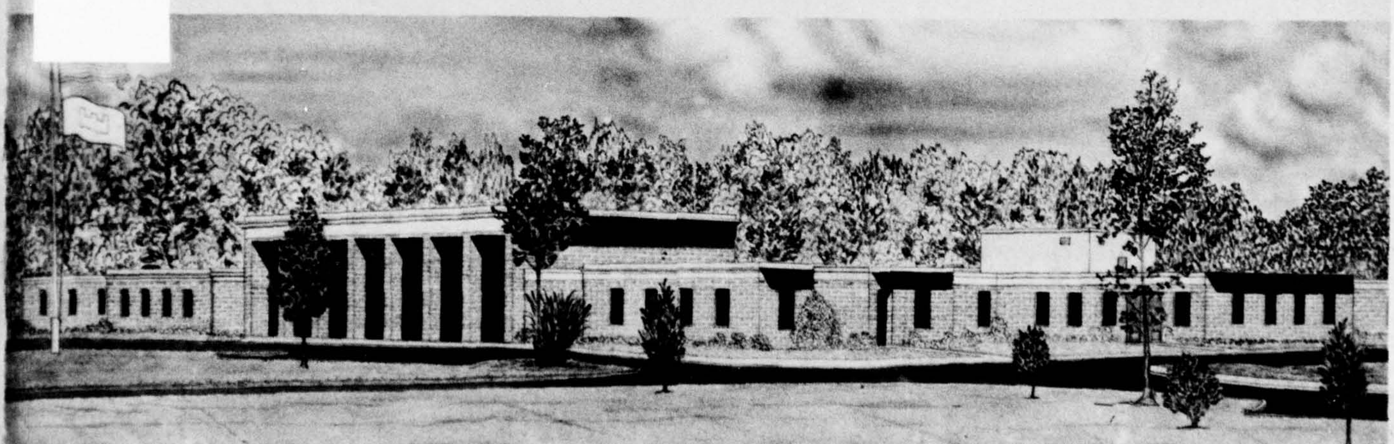
by

Edward D. Rothwell

Hydraulics Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

October 1976

Final Report



Prepared for U. S. Army Engineer District, Fort Worth
Fort Worth, Texas 76102

T. R. H-76-10 NORTH FORK LAKE SPILLWAY, SAN GABRIEL RIVER, TEXAS OCT. 1976

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The spillway for North Fork Lake Dam will consist of a 1000-ft-wide uncontrolled broad-crested weir excavated in limestone located in the right abutment of the dam. An outlet works consisting of two flood-control and four low-flow inlets will discharge into a hydraulic-jump-type stilling basin and exit channel located on the downstream side of the earth-filled dam.

Model investigations were conducted using a 1:80-scale model to develop a

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20. ABSTRACT (Continued).

design that would eliminate the destructive currents along the toe of the earth-fill dam embankment and in the vicinity of the outlet works stilling basin and spillway discharge channel. The model was also used to measure velocities, surging, and flow patterns for several discharges in the approach and discharge channels and to determine the design of a rockfill dike at the upstream left abutment of the spillway.

Tests indicated that a 100-ft-long elliptical-shaped dike would be required in the vicinity of the upstream left abutment to provide protection for the dam embankment and retaining wall. The minimum stone size (d_{50} = 16 in.) required for stability of the upstream rockfill dike was determined from the model. The hydraulic performance of the spillway crest design was satisfactory for a range of anticipated discharges.

The model investigation also indicated that additional protection would be required in the exit channel and the San Gabriel River basin to ensure the stability of the dam embankment against scour. Excavation along the downstream right bluff of the spillway exit channel and two rockfill dikes located along the left bank of the San Gabriel River (No. 1 dike) and the dam embankment (No. 2 dike) will provide adequate protection of the dam embankment.

The minimum stone size (d_{50} = 25 in.) required for stability of the two downstream rockfill dikes was determined from the model.

PREFACE

The model investigation reported herein was authorized by the Office, Chief of Engineers, U. S. Army, on 28 May 1974, at the request of the U. S. Army Engineer District, Fort Worth.

The study was conducted during the period May 1974 to May 1975 in the Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES) under the direction of Mr. H. B. Simmons, Chief of the Hydraulics Laboratory, and under the general supervision of Messrs. J. L. Grace, Jr., Chief of the Structures Division, and J. P. Bohan, Chief of the Spillways and Channels Branch. The project engineer for the model study was Mr. E. D. Rothwell, assisted by Mr. B. Perkins. This report was prepared by Mr. Rothwell.

During the course of the investigation, Messrs. W. P. Johnson, Jr., T. Schmidgall, C. F. Berryhill, C. H. Sullivan, and R. L. James of the U. S. Army Engineer Division, Southwestern; Messrs. G. W. Demeritt, R. A. Wurbs, S. T. Maynord, R. Turner, G. Carefoot, H. Karbs, W. Shaver, and L. Wong of the Fort Worth District; and Messrs. K. Zahm and E. M. Quintana of the Albuquerque District visited WES to discuss the program and results of model tests, observe the model in operation, and correlate these results with design studies.

Directors of WES during the conduct of the study and the preparation and publication of this report were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
feet	0.3048	metres
miles (U. S. statute)	1.609344	kilometres
square miles	2.589988	square kilometres
cubic yards	0.7645549	cubic metres
acre-feet	1233.482	cubic metres
feet per second	0.3048	metres per second
cubic feet per second	0.02831685	cubic metres per second

Figure 1. Vicinity map

NORTH FORK LAKE SPILLWAY

SAN GABRIEL RIVER, TEXAS

Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

1. The North Fork Lake Dam will be located at river mile 4.3 on the north fork of the San Gabriel River, Texas. The site for the dam is about 3.5 miles* west of Georgetown, Texas. The reservoir will be located entirely within Williamson County, Texas (Figure 1). The dam will be a rock and earthfill zoned embankment having a maximum height of 161 ft (el 861.0**) above the riverbed, an overall length of 6,640 ft, and a crown width of 30 ft. The reservoir will have a 246-square-mile drainage area and will provide a gross storage capacity of 130,800 acre-ft at the top of the flood control pool, el 834.0.

2. The spillway will consist of a 1,000-ft-wide uncontrolled broad-crested weir excavated in limestone with crest elevation 834.0 located in the right abutment of the dam. The spillway will be designed to discharge 284,000 cfs at reservoir el 856.2.

3. The flow area of the spillway will be trapezoidal in shape with a 1000-ft bottom width, 4V on 1H side slopes in rock cut, and 1V on 2H side slopes in the overburden. The channel will be horizontal for a distance of 100 ft upstream from the control section and then slope downward at a 1 percent grade for a distance of 1000 ft to el 824.0. The remainder of the spillway approach channel will be cut horizontal at el 824.0. The spillway discharge channel, downstream from the control section, will slope downward on a grade of 1.5 percent to natural

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

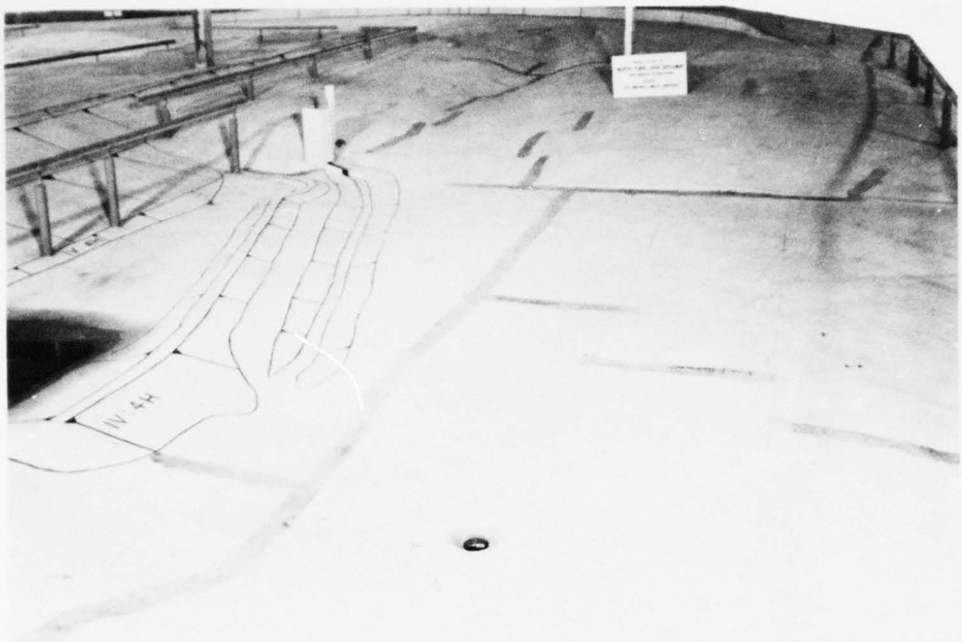
** All elevations (el) cited herein are in feet referred to mean sea level.

ground. A natural ravine extends for approximately 1600 ft from the spillway discharge channel downstream to the San Gabriel River. The spillway approach channel will have a 950-ft-radius curve and the discharge channel a 900-ft-radius curve (Figure 2).

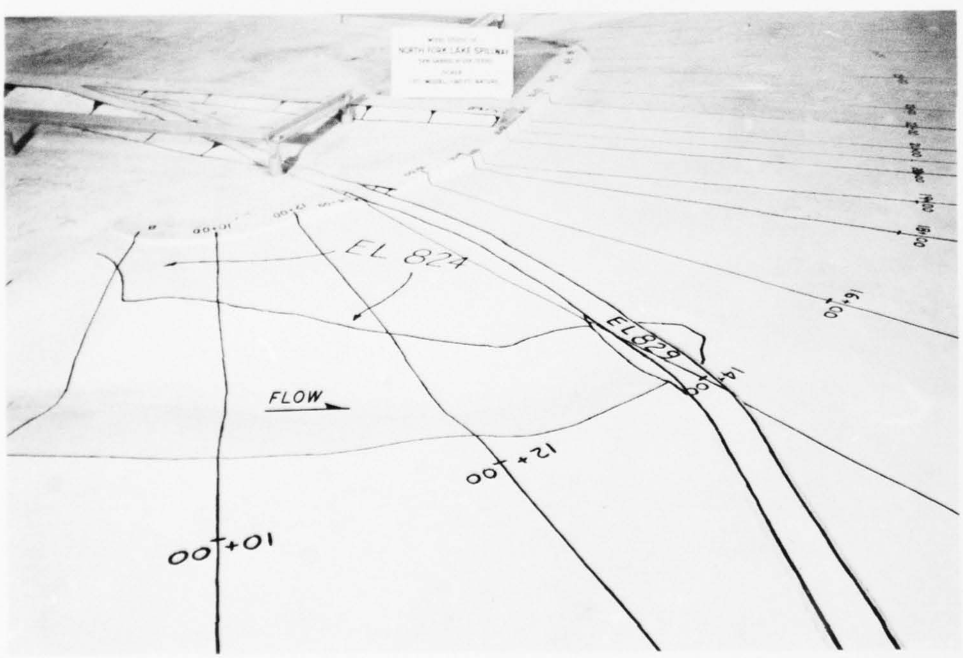
4. The outlet works will include two flood-control and four low-flow inlets, which will discharge into an 11-ft-diam tunnel having an overall length of 1286 ft. The flood-control gates, with inverts at el 720.0, will be 5.0 ft wide by 11.0 ft high. The low-flow gated intakes will be 3.0 ft wide by 4.0 ft high with inverts at el 738.5, 751.33, 764.17, and 777.0. The outlet works is designed to pass an outflow of 4500 cfs at reservoir el 856.0.

Purpose of Model Study

5. The model tests were conducted to develop a design which would eliminate the destructive currents along the toe of the dam embankment and in the vicinity of the outlet works stilling basin and spillway discharge channel. The model was also utilized to measure velocities, surging, and flow patterns for several discharges in the approach and discharge channels and to determine the adequacy of constructing a rockfill dike at the upstream left abutment of the spillway.



a. Looking upstream, upstream approach channel and intake structure



b. Approach channel, upstream left abutment

Figure 2. The 1:80-scale comprehensive model (sheet 1 of 3)

c. Downstream spillway and discharge channel

d. Exit channel and outlet works stilling basin

Figure 2 (sheet 2 of 3)

e. Dam embankment and stone protection

Figure 2 (sheet 3 of 3)

PART II: THE MODEL

Description

6. A 1:80-scale model was constructed to reproduce all topography and structures in an area extending 2350 ft upstream and 3000 ft downstream from the centerline of the dam embankment and 500 ft to the right and 4600 ft to the left of the centerline of the spillway (Figure 2 and Plate 1). The portions of the model representing the approach, exit, and overbank areas were molded of cement mortar to sheet metal templates and were given a brushed finish. The uncontrolled broad-crested weir was fabricated of sheet metal (Plate 2). The outlet works and stilling basin were constructed of plastic-coated plywood.

7. Water used in the operation of the model was supplied by pumps, and discharges were measured with venturi meters. Steel rails set to grade provided reference planes for measuring devices. Water surface elevations were obtained with point gages. Velocities were measured with a pitot tube and by timing the movement of flotage and dye over measured distances. Current patterns were determined by observing the movement of dye injected into the water and confetti sprinkled on the water surface.

Scale Relations

8. The accepted equations of hydraulic similitude, based upon Froudian criteria, were used to express the mathematical relations between the dimensions and hydraulic quantities of the model and prototype. The general relations expressed in terms of the model scale or length ratio, L_r, are presented in the following tabulation:

Dimensions	Ratio	Scale Relation
Length	L_r	1:80
Area	$A_r = L_r^2$	1:6,400

(Continued)

Dimensions	Ratio	Scale Relation
Velocity	$V_r = L_r^{1/2}$	1:8.9443
Discharge	$Q_r = L_r^{5/2}$	1:57,243.52
Time	$T_r = L_r^{1/2}$	1:8.9443
Volume	$V_r = L_r^3$	1:512,000

9. Model measurements of each dimension or variable can be transferred quantitatively to prototype equivalents by means of the preceding scale relations.

PART III: TESTS AND RESULTS

Approach Channel Area

10. The approach area reproduced in the model extended 2,350 ft upstream from the centerline of the dam embankment (Figure 2 and Plate 1). Velocities and flow patterns in the approach channel were measured at 100-ft intervals to the right and left of the centerline of the channel and for a distance of 1,450 ft upstream from the centerline of the spillway (Plate 3 and Photo 1). These velocities were taken at 0.6 depth below the water surface for discharges of 88,000 and 284,000 cfs and pool el of 845.0 and 856.6, respectively, as shown in Plate 3.

Discharge Channel Area

11. The entire spillway discharge and exit channel area from the centerline of the spillway downstream for 4,450 ft (Figure 2 and Plate 1) was reproduced in the model. Flow conditions were investigated for a range of uncontrolled discharges including 78,000 cfs (standard project flood) and 284,000 cfs (spillway design flood). These flows were concentrated along the right side of the spillway channel downstream from the control weir. This situation caused flooding in the ravine, located to the right of the spillway channel, and produced irregular flow patterns in the exit channel below the spillway (Photo 2). Velocities and flow patterns in the spillway, downstream of the control weir, and in the exit channel were measured at 150-ft intervals in the spillway and 50-ft intervals in the exit channel to the right and left of the respective centerlines (Plate 4 and Photo 3). These velocities were taken at 0.6 depth below the water surface for discharges of 88,000 and 284,000 cfs and pool el of 845.0 and 856.6, respectively, as shown in Plate 4. Wave heights resulting from surging along the left bank of the San Gabriel River and along the toe of the dam embankment are also shown in Plate 4.

Spillway and Left Abutment

Original design

12. Details of the spillway crest and left abutment design are presented in Plate 2 and Photo 4. Initial tests were conducted to determine velocities, water surface elevations, and general flow patterns across the spillway crest for a range of discharges. Velocities measured at 0.6 depth below the water surface at several locations and for a range of discharges and pool elevations are presented in Tables 1-3. Velocities were also measured at the centerline of the spillway crest (sta 20+50) for discharges of 100,000, 150,000, and 190,000 cfs and pool el of 846.0, 849.2, and 851.6, respectively (Table 4). Water surface elevations across the centerline of the crest measured for a range of discharges are presented in Table 5. The model tests indicated satisfactory performance of the weir for the expected range of discharges; therefore, no alterations were made in the design during the study.

Uncontrolled flow

13. An uncontrolled-flow rating curve is included in Plate 5. The head to discharge relationship for uncontrolled flow was determined from basic data obtained in the model (Table 6). The following equation satisfies this calibration data:

$$Q = 1.55LH^{1.69}$$

where

Q = total discharge, cfs

L = net length of spillway, ft

H = total head on crest (including approach velocity head), ft

A comparison of the actual model and computed uncontrolled rating curves is presented in Plate 6. The discrepancy between the curves is attributed to the flow contraction which exists at the left abutment (Photo 4).

Left Abutment Rockfill Dike

14. Tests were conducted in the vicinity of the upstream left abutment to determine the flow conditions associated with various discharges. The magnitude and direction of average velocities (measured at 0.6 depth of flow) at the original left abutment are shown in Plate 7 and Photo 4. These tests indicated that a reduction in the magnitude and direction of average velocities along the upstream dam embankment and around the retaining wall would be required to ensure stability of the left abutment. The Fort Worth District (SWF) furnished details of the proposed rockfill dike to be located in the vicinity of the upstream left abutment (Plate 8 and Photo 5). Test results with the proposed design indicated that the magnitude and direction of average velocities were sufficiently reduced in the vicinity of the spillway left abutment to provide adequate protection of the dam embankment and retaining wall (Plate 7). However, increased velocities were observed in the vicinity of the south access road approach to the spillway (sta 12+00 and 14+00) as compared to those observed with the original left abutment (Plate 7).

15. Several alternative designs were studied with the conclusion that a smaller rockfill dike would decrease the magnitude of the average velocities in the vicinity of the south access road approach to the spillway, while adequately protecting the dam embankment and retaining wall. SWF furnished details of three alternative rockfill dikes. With each dike design, the magnitudes of the average velocities in the vicinity of the spillway left abutment were sufficiently reduced to provide adequate protection of the dam embankment and retaining wall while at the same time reducing the severe flow conditions produced at the south access road approach to the spillway. However, the 100-ft-long elliptical shaped dike (Figure 3 and Plate 9) provided a more uniform flow distribution along the left side of the spillway approach channel. Velocities associated with the proposed and alternate rockfill dikes are shown in Table 7.

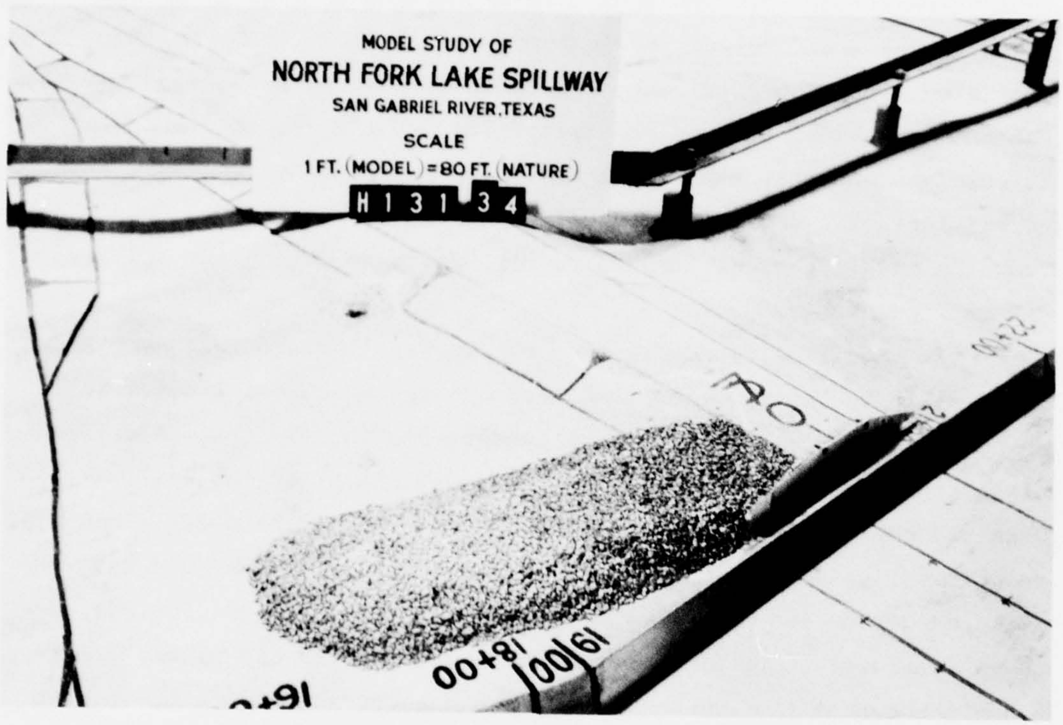


Figure 3. Final design (100-ft-long elliptical dike) at left abutment of spillway

Exit Channel

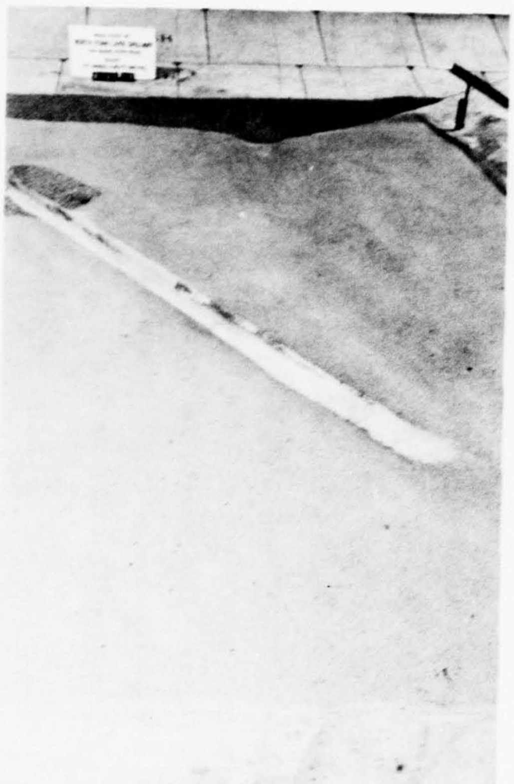
Original design

16. The exit channel extends from sta 37+00 downstream to the San Gabriel River basin channel, approximately 2800 ft. Flow conditions in the exit channel were observed and measured for several discharges with the original topography simulated in the channel (Photo 6). A discharge of 88,000 cfs produced average velocities of less than 6 fps (prototype) along the downstream toe of the dam embankment (Photo 3 and Plate 4). Average velocities in excess of 25 fps (prototype) were generated along the left bank of the San Gabriel River and the toe of the dam embankment for a discharge of 284,000 cfs (Photo 3 and Plate 4). It was apparent that modifications to the exit channel would be required to eliminate the severe damage caused at the toe of the dam embankment from the highly concentrated velocities produced during the spillway design flood (284,000 cfs).

17. Modifications were made to simulate the erodible overburden material in the spillway exit channel and the San Gabriel River basin as shown in Figure 4 Tests were conducted with the original design simulating the 120-hr outflow hydrograph (Table 8) of the spillway design flood (284,000 cfs) for a duration of 8 hr in the model (Photo 7). Velocities, general flow patterns, and surge heights observed and measured during the peak discharge of the hydrograph (284,000 cfs) are shown in Plates 4 and 10. Considerable movement of the riprap occurred along the toe of the dam embankment and a large amount of this riprap, as well as the erodible material, was deposited in the vicinity of the outlet works exit channel (Photo 8). It was concluded that modifications to the exit channel draw would be required to eliminate or reduce the high velocity and circulation pattern which eroded the riprap at the toe of the dam embankment and deposited it in the outlet works exit channel.

Modification to the exit channel

18. Several schemes of excavations along the downstream right



a. San Gabriel River basin

b. Spillway exit channel and outlet works channel

c. Toe of dam embankment and outlet works

Figure 4. Exit channel and San Gabriel River basin sand model

side of the spillway exit channel were investigated to try to develop a satisfactory design which would reduce the magnitude and alter the direction of velocities along the toe of the dam embankment. The most improved flow condition was obtained by excavating approximately 13,000 cu yd of overburden and rock material between sta 48+00 and 57+00 as shown in Plate 11. Velocities and general flow patterns observed and measured during the peak discharge of the hydrograph are shown in Plate 10. This modification to the right bluff of the spillway exit channel reduced the magnitude of the velocities at the toe of the dam embankment by diverting the point of flow concentration approximately 200 ft farther downstream on the left bank of the San Gabriel River. However, it appeared from the above test results that a combination of excavation along the downstream right bluff and two rockfill dikes located along the left bank of the San Gabriel River and the dam embankment would be required to ensure adequate protection of the dam embankment.

Rockfill dikes

19. Tests conducted to determine the location and alignment of the two rockfill dikes indicated that the San Gabriel River Dike (No. 1 dike) and the dam embankment dike (No. 2 dike) should be located approximately 600 ft downstream from the dam embankment (el 753) on the left bank of the San Gabriel River and 600 ft downstream from the centerline of the dam at sta 36+65, respectively (Figures 5 and 6). The effectiveness of the Type 1 design rockfill dikes (d_{50} = 40 in.) located along the left bank of the San Gabriel River and the dam embankment, in conjunction with the excavation along the downstream right bluff of the spillway exit channel, is shown in Photo 9. The improved flow conditions resulting with this configuration reduced the magnitude of velocities and altered the direction of flow along the toe of the dam embankment sufficiently to prevent excessive scour (Plate 12). However, the cost of providing the required average stone size (d_{50} = 40 in.) would be extremely high even if the 40-in. stone was available. Therefore, additional tests were conducted to determine the velocities and flow directions associated with dikes having d_{50} stone of 25 in.

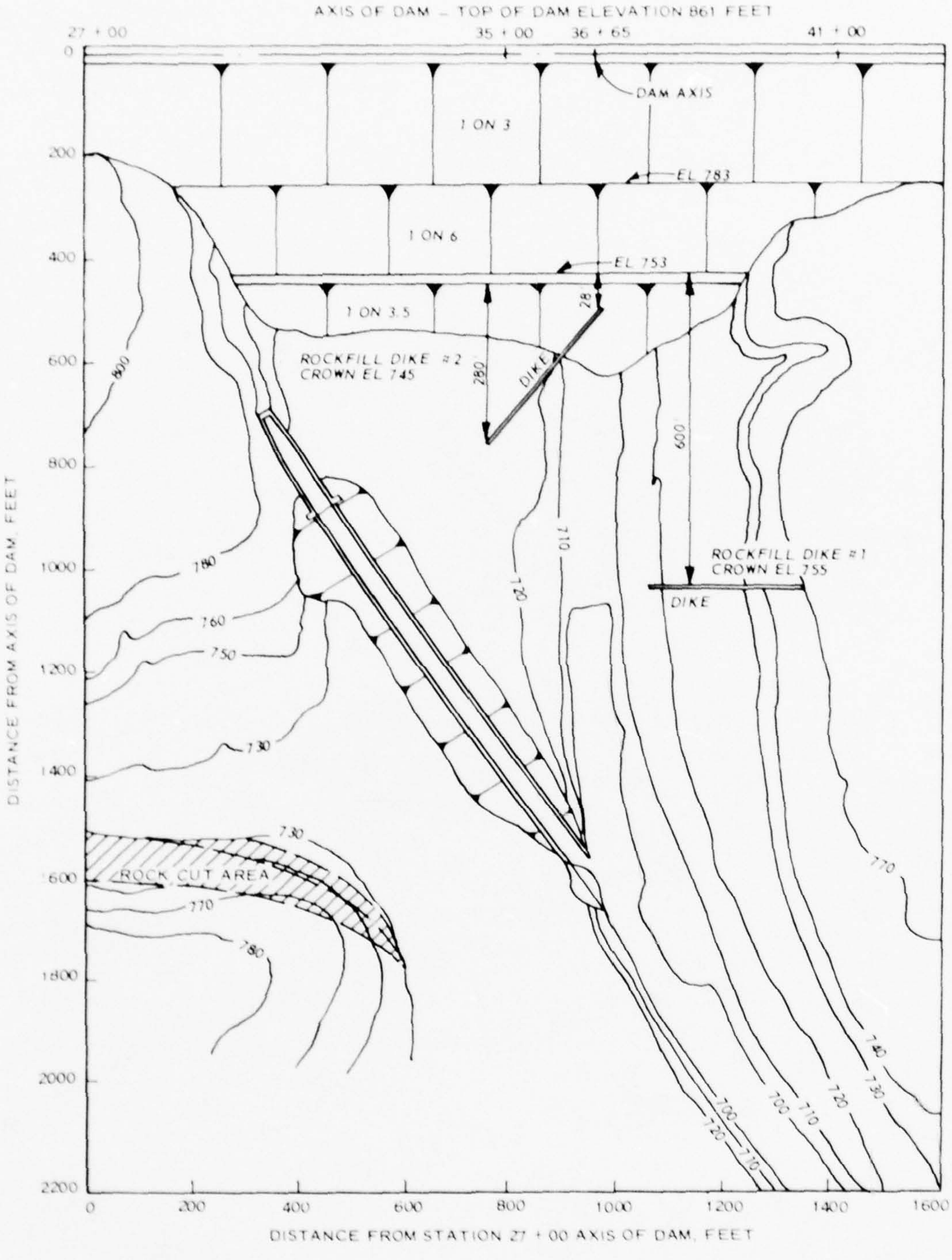


Figure 5. Details of Type 1 design rockfill dikes

a. Closeup view

b. Overall view

Figure 6. Location of rockfill dikes in the San Gabriel River basin

Alternative rockfill dikes

20. The Type 2 rockfill dike design is shown in Figure 7. Velocities and general flow patterns observed in the spillway exit channel and the San Gabriel River basin (Plate 12) during the peak discharge of the hydrograph (284,000 cfs) indicated that this design would provide adequate protection along the dam embankment (Photo 10a). The Type 3 design of rockfill dike No. 1, which consisted of a dike length of 150 ft, was insufficient to prevent scour along the toe of the dam embankment (Photo 10b). Results with the Type 4 design (Figures 8 and 9) indicated that this design would provide adequate protection along the dam embankment (Photo 11). Velocities and general flow patterns observed in the spillway exit channel and the San Gabriel River basin during the peak discharge of the hydrograph (284,000 cfs) are shown in Plate 13. These studies indicate that either the Type 2 or Type 4 design dikes consisting of an average stone size (d_{50}) of 25 in. would be sufficient to ensure the stability of the dam embankment.

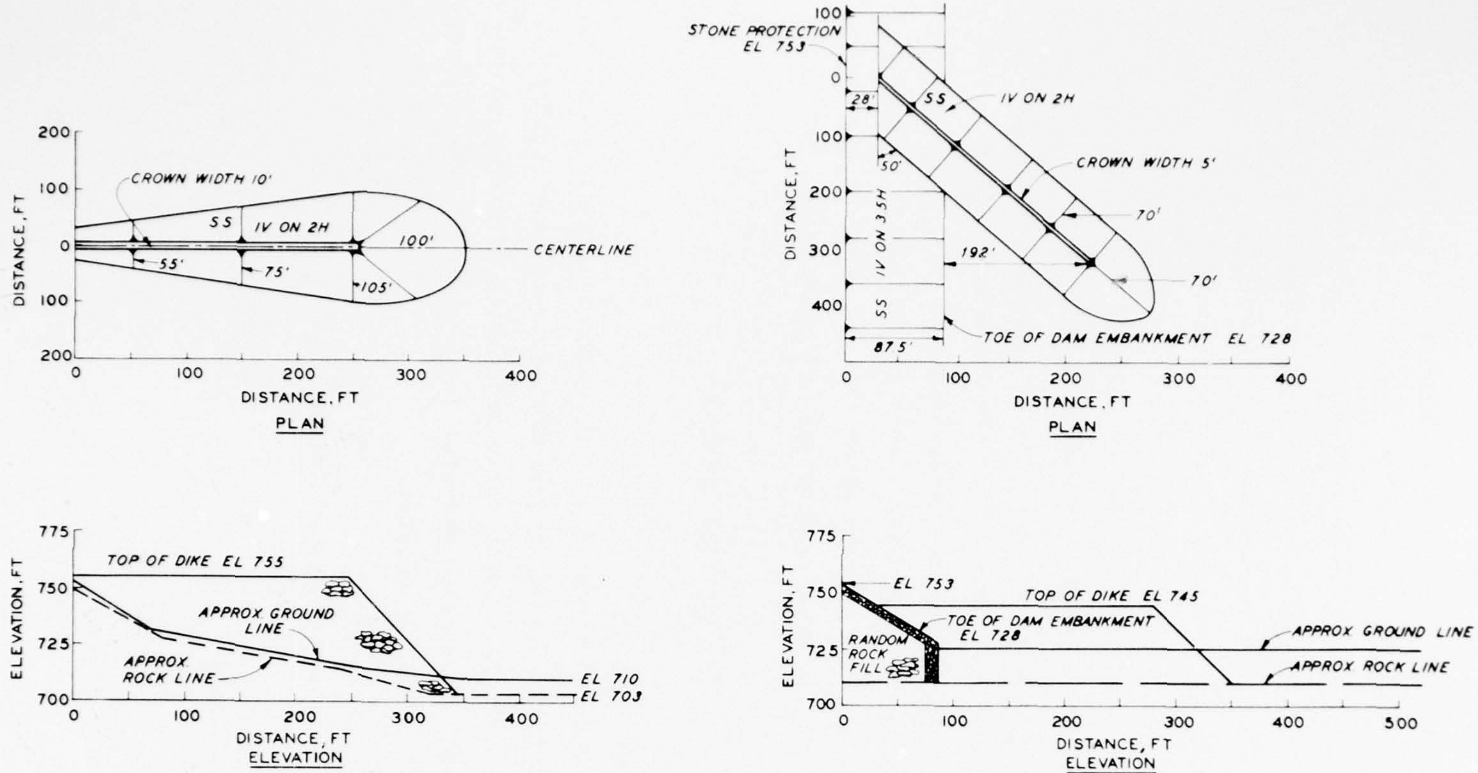
Rockfill Dike Gradation

Upstream left abutment dike

21. Stone protection simulating a d_{50} stone of 16 in. was used to construct the rockfill dike located at the upstream left abutment of the spillway. Subsequent tests with various rockfill dike designs indicated that stone with an average diameter (d_{50}) of 16 in. would remain stable under all anticipated discharges.

22. Based on a d_{50} of 16 in., the following gradation is considered adequate for stability of the upstream rockfill dike:

Stone Diameter, in.	Percent Finer by Weight
30	85-100
25	50-85
16	15-50
7	0-15



DESIGN: CROWN ELEVATION 755
CROWN WIDTH 10'
CROWN LENGTH 250'
SIDE SLOPE 1V ON 2H
D_{50} = 25 IN.

GROUND CONTOUR	
DISTANCE	ELEVATION
0	755
10	750
40	740
70	730
200	720
250	715

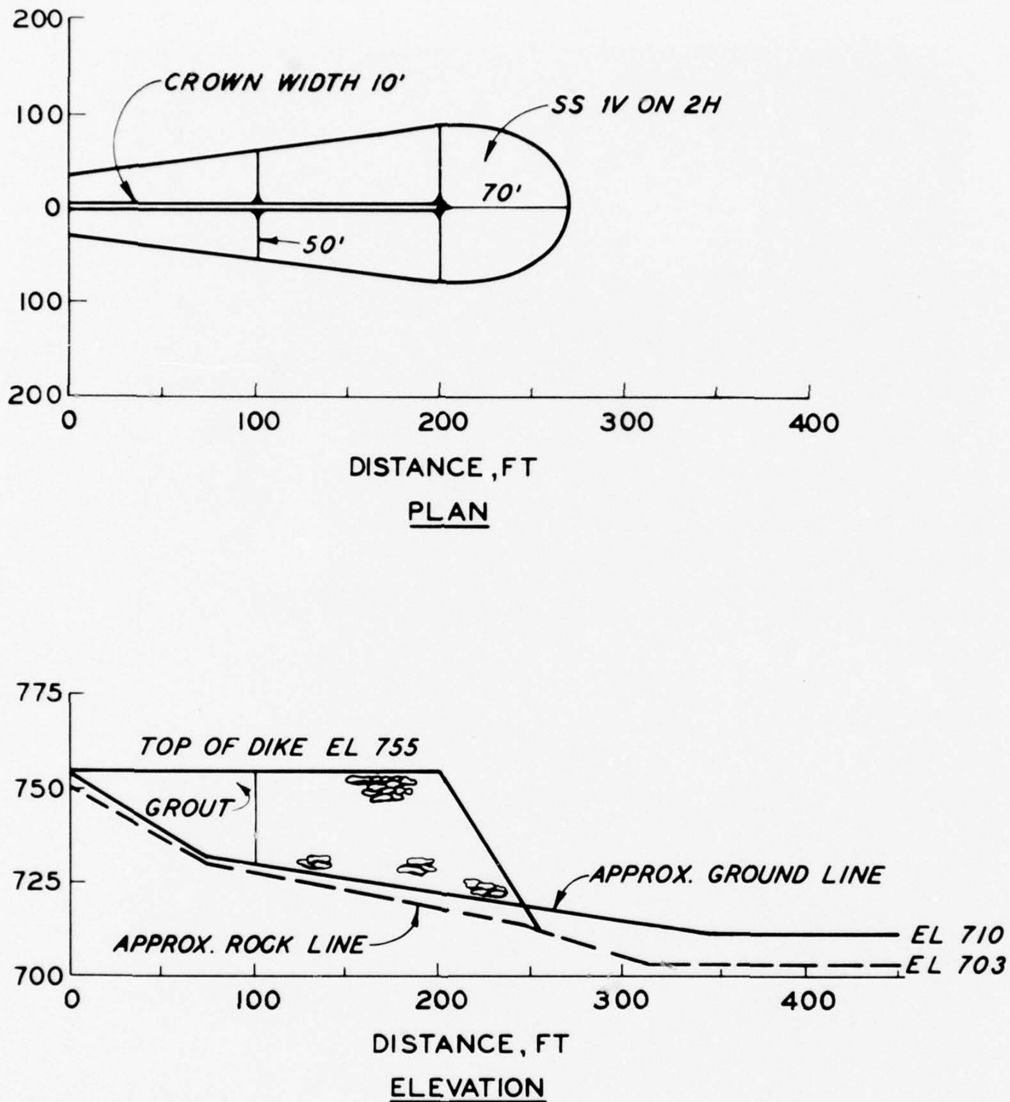
ROCK CONTOUR	
DISTANCE	ELEVATION
0	750
80	728
160	721
240	714
320	703

a. ROCKFILL DIKE NO. 1,
LEFT BANK OF SAN GABRIEL RIVER

DESIGN: CROWN ELEVATION 745
CROWN WIDTH 5'
CROWN LENGTH 250'
SIDE SLOPE 1V ON 2H
D_{50} = 25 IN.

b. ROCKFILL DIKE NO. 2,
TOE OF DAM EMBANKMENT

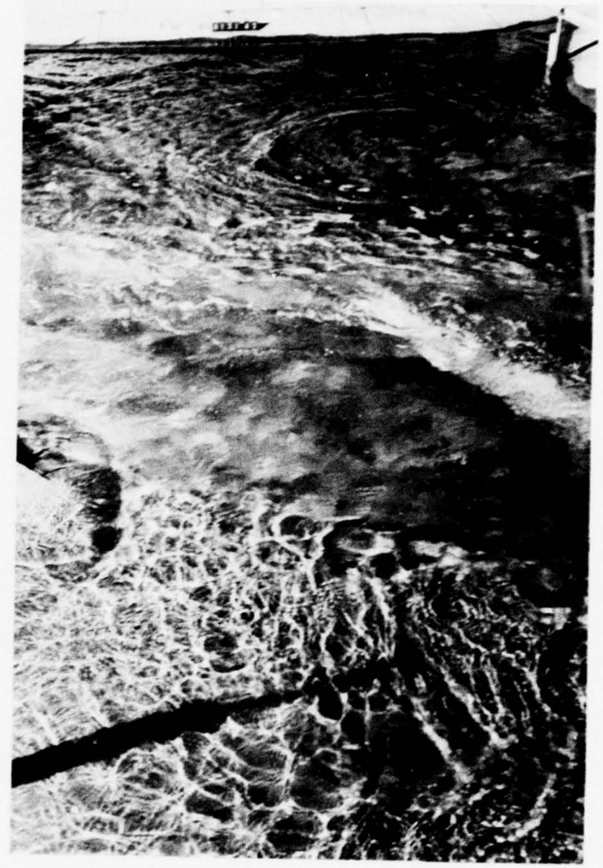
Figure 7. Details of Type 2 design rockfill dikes



DESIGN: CROWN ELEVATION 755
CROWN WIDTH 10'
CROWN LENGTH 200', 100' GROUTED
SIDE SLOPE 1V ON 2H
D_{50} = 25 IN.

Figure 8. Details of Type 4 (recommended) design rockfill dike # 1, left bank of San Gabriel River

a. Dry-bed view



b. Discharge, 284,000 cfs;
pool el, 856.5;
tailwater el, 752.0

Figure 9. Type 4 (recommended) design rockfill dikes

Downstream San Gabriel
River dikes

23. Model results indicate that the downstream San Gabriel River dikes (Figures 7 and 8) constructed of d_{50} stone of 25 in. would provide adequate protection along the toe of the dam embankment. The following gradation is recommended based on a d_{50} of 25 in. for these dikes:

Stone Diameter, in.	Percent Finer by Weight
45	85-100
40	50-85
25	15-50
11	0-15

PART IV: DISCUSSION

24. The hydraulic model investigation of the North Fork Lake Spillway revealed the general adequacy of the overall design of the structure and discharge channels. Minor modifications were required in the vicinity of the upstream left abutment to improve the hydraulic performance and provide protection for the dam embankment and retaining wall. Major modifications were required in the exit channel and along the left bank of the San Gabriel River to provide adequate protection of the downstream dam embankment.

25. The performance of the spillway crest design was satisfactory, and no alterations were made during the study. However, the model indicated that flow concentrated along the right side of the spillway channel downstream from the control weir. This situation caused flooding in the ravine located to the right of the spillway channel and irregular flow patterns in the exit channel below the spillway. This condition was expected and would be permissible in the prototype and therefore no alterations were considered in the model.

26. Although the original proposed rockfill dike located at the upstream left abutment of the spillway performed satisfactorily to provide adequate protection of the dam embankment and retaining wall, it was found that better economics and flow conditions in the vicinity of the south access road approach to the spillway could be effected by reducing the overall dimensions of the rockfill dike structure. Several dike designs were studied which sufficiently reduced the magnitude of the average velocities in the vicinity of the spillway left abutment while providing adequate protection of the dam embankment and retaining wall. The 100-ft-long elliptical shaped dike design (Plate 9) provided a more uniform flow distribution along the left side of the spillway approach channel and, therefore, is the recommended design.

27. The model study also indicated that additional protection would be required in the exit channel and the San Gabriel River basin to ensure the stability of the dam embankment against scour. Excavation along the downstream right bluff of the spillway exit channel and two

rockfill dikes located along the left bank of the San Gabriel River (No. 1 dike) and the dam embankment (No. 2 dike) will provide adequate protection of the dam embankment. These studies indicated that either the Type 2 or Type 4 design dikes constructed of riprap with an average diameter of 25 in. would be sufficient to ensure the stability of the dam embankment. It is the opinion of WES hydraulic engineers that the Type 4 design will provide additional protection due to the grouting of the 100-ft length of dike No. 1 adjacent to the left riverbank and, therefore, it is the recommended design. In addition, modifications were made to the original plans and specifications for the dam embankment construction to include the excavation of the overburden material and placement of additional stone protection at the toe of the dam embankment to existing rock.

Table 1

Velocity and Flow Observations at the Spillway

Discharge: 78,000 cfs - Design: Original - Pool El: 844.2 - Tailwater El: 728.0

Station No.	Distance from Centerline, ft Left	Distance from Centerline, ft Right	Direction Measured in Degrees Right	Average Velocity fps	Station No.	Distance from Centerline, ft Left	Distance from Centerline, ft Right	Direction Measured in Degrees Right	Average Velocity fps	Station No.	Distance from Centerline, ft Left	Distance from Centerline, ft Right	Direction Measured in Degrees Right	Average Velocity fps
20+00			5	12.4	20+50			5	12.5	21+00			0	13.2
		50	5	12.0			50	5	12.0			50	5	13.2
		100	5	12.0			100	10	12.0			100	5	13.0
		150	10	11.8			150	10	11.8			150	5	12.4
		200	10	11.5			200	10	11.8			200	5	12.4
		250	10	11.2			250	5	11.5			250	10	12.4
		300	5	11.2			300	5	11.5			300	10	12.0
		350	10	11.2			350	5	11.0			350	10	11.8
		400	5	10.9			400	0	11.0			400	10	11.5
		450	0	10.9			450	0	11.0			450	5	11.5
		495	0	10.9			495	0	10.9			495	5	11.1
	50		0	12.5		50		0	12.5		50		0	13.4
	100		0	12.9		100		5	12.9		100		5	13.7
	150		5	13.0		150		5	13.1		150		5	13.7
	200		10	13.0		200		5	13.2		200		10	13.7
	250		10	13.4		250		5	13.7		250		10	13.9
	300		10	13.7		300		5	14.0		300		10	14.4
	350		5	13.7		350		5	14.2		350		10	14.8
	400		0	13.9		400		0	14.2		400		5	15.0
	450		0	13.2		450		0	14.0		450		0	14.5
	495		0	6.4		495		0	9.8		495		0	10.9

Note: Velocity directions were measured from a line perpendicular to the crest axis.

Table 2

Velocity and Flow Observations at the Spillway

Discharge: 88,000 cfs - Design: Original - Pool El: 845.0 - Tailwater: 731.0

Station No.	Distance from Centerline, ft Left	Right	Direction Measured in Degrees Right	Average Velocity fps	Station No.	Distance from Centerline, ft Left	Right	Direction Measured in Degrees Right	Average Velocity fps	Station No.	Distance from Centerline, ft Left	Right	Direction Measured in Degrees Right	Average Velocity fps
20+00			10	12.4	20+50			5	13.0	21+00			5	14.7
		50	10	12.4			50	5	13.2			50	5	15.0
		100	10	12.4			100	5	13.2			100	5	15.0
		150	10	12.0			150	5	13.0			150	10	14.4
		200	10	12.0			200	5	13.2			200	10	14.4
		250	10	12.0			250	5	12.4			250	10	14.0
		300	10	12.0			300	5	12.4			300	10	14.0
		350	10	12.0			350	5	12.4			350	10	14.0
		400	5	12.0			400	0	12.0			400	5	14.0
		450	0	11.8			450	0	11.5			450	0	14.0
		495	0	11.5			495	0	11.5			495	0	13.7
	50		10	13.2		50		10	13.2		50		5	14.7
	100		10	13.2		100		10	13.7		100		5	14.7
	150		10	13.2		150		10	13.7		150		10	14.7
	200		10	14.0		200		10	13.7		200		10	15.0
	250		10	14.0		250		10	14.0		250		10	15.0
	300		10	14.0		300		10	15.0		300		10	15.8
	350		10	14.0		350		10	15.8		350		10	17.0
	400		5	14.0		400		5	15.8		400		5	17.0
	450		5	14.4		450		0	15.4		450		5	16.4
	495		0	7.8		495		0	10.7		495		0	15.8

Note: Velocity directions were measured from a line perpendicular to the crest axis.

Table 3

Velocity and Flow Observations at the Spillway

Discharge: 284,000 cfs - Design: Original - Pool El: 856.6 - Tailwater El: 752.0

Station No.	Distance from Centerline, ft Left	Right	Direction Measured in Degrees Right	Average Velocity fps	Station No.	Distance from Centerline, ft Left	Right	Direction Measured in Degrees Right	Average Velocity fps	Station No.	Distance from Centerline, ft Left	Right	Direction Measured in Degrees Right	Average Velocity fps
20+00			0	19.0	20+50			0	20.0	21+00			0	20.3
		50	5	18.8			50	0	19.0			50	0	20.1
		100	10	18.0			100	5	18.5			100	5	20.1
		150	10	17.5			150	5	18.5			150	10	20.0
		200	10	17.6			200	5	18.0			200	10	20.0
		250	5	17.5			250	5	18.0			250	10	20.1
		300	5	17.0			300	5	18.0			300	15	20.1
		350	5	16.8			350	5	18.0			350	10	20.1
		400	5	16.5			400	10	17.8			400	5	20.1
		450	0	16.3			450	0	17.7			450	5	19.3
		495	0	16.0			495	0	17.6			495	0	19.3
	50		10	19.0		50		0	20.5		50		5	20.5
	100		10	19.0		100		5	21.0		100		5	21.4
	150		10	19.2		150		10	21.4		150		10	23.0
	200		10	20.2		200		10	21.8		200		10	23.3
	250		15	21.0		250		10	23.4		250		10	24.4
	300		15	21.8		300		5	24.5		300		10	25.0
	350		15	23.1		350		5	23.4		350		10	25.6
	400		10	15.0		400		5	18.5		400		10	19.5
	450		0	13.7		450		0	16.4		450		0	17.8
	495		0	13.0		495		0	10.2		495		0	11.5

Note: Velocity directions were measured from a line perpendicular to the crest axis.

Table 4

Velocity and Flow Observations at the Spillway

Discharge: 100,000 cfs - Design: Original - Pool El: 846.0 - Tailwater El: 732.0

Station No.	Distance from Centerline, ft Left	Distance from Centerline, ft Right	Direction Measured in Degrees Right	Average Velocity fps
20+50			0	13.7
		50	0	13.2
		100	0	13.2
		150	0	13.7
		200	0	14.0
		250	0	13.7
		300	0	13.2
		350	0	13.0
		400	0	13.0
		450	0	13.0
		495	0	13.0
	50		355	13.0
	100		355	13.2
	150		355	14.0
	200		355	15.0
	250		355	16.0
	300		355	16.4
	350		0	16.7
	400		0	16.4
	450		0	16.0
	495		0	7.2

Discharge: 150,000 cfs - Design: Original - Pool El: 849.2 - Tailwater El: 739.0

Station No.	Distance from Centerline, ft Left	Distance from Centerline, ft Right	Direction Measured in Degrees Right	Average Velocity fps
20+50			355	15.8
		50	355	15.4
		100	355	15.4
		150	355	15.0
		200	355	14.4
		250	0	14.7
		300	0	15.0
		350	0	15.0
		400	0	14.4
		450	0	14.4
		495	0	14.4
	50		355	15.4
	100		355	16.4
	150		355	17.6
	200		355	17.6
	250		355	19.0
	300		355	19.3
	350		0	19.3
	400		0	19.5
	450		5	18.5
	495		0	8.4

Discharge: 190,000 cfs - Design: Original - Pool El: 851.6 - Tailwater El: 743.4

Station No.	Distance from Centerline, ft Left	Distance from Centerline, ft Right	Direction Measured in Degrees Right	Average Velocity fps
20+50			355	17.0
		50	355	16.0
		100	355	15.8
		150	355	15.4
		200	355	15.4
		250	355	15.8
		300	0	16.0
		350	0	15.8
		400	0	15.4
		450	0	15.4
		495	0	15.8
	50		355	17.0
	100		355	17.8
	150		355	18.5
	200		355	20.1
	250		355	20.1
	300		355	20.1
	350		0	20.3
	400		0	22.0
	450		0	14.0
	495		0	9.6

Note: Velocity directions were measured from a line perpendicular to the crest axis.

Table 5

Water Surface Elevations Along Centerline of Spillway Crest

Crest Elevation 834.0

Station No.	Distance from Centerline, ft Left	Right	Water Surface Elevation Above Crest	Station No.	Distance from Centerline, ft Left	Right	Water Surface Elevation Above Crest	Station No.	Distance from Centerline, ft Left	Right	Water Surface Elevation Above Crest
Discharge: 78,000 cfs; Pool Elevation: 844.2 ft				Discharge: 88,000 cfs; Pool Elevation: 845.0 ft				Discharge: 100,000 cfs; Pool Elevation: 846.0 ft			
20+50			840.64	20+50			840.88	20+50			842.08
		50	840.64			50	840.80			50	841.84
		100	840.72			100	840.96			100	841.92
		150	840.88			150	841.12			150	841.92
		200	840.88			200	841.12			200	841.92
		250	840.96			250	841.20			250	841.92
		300	841.04			300	841.28			300	842.00
		350	841.12			350	841.36			350	842.00
		400	841.20			400	841.36			400	842.08
		450	840.88			450	841.44			450	842.08
		495	840.88			495	841.44			495	842.08
	50		840.48		50		840.88		50		842.00
	100		840.56		100		840.80		100		841.68
	150		840.46		150		840.64		150		841.04
	200		840.16		200		840.32		200		840.94
	250		839.50		250		839.68		250		840.40
	300		839.48		300		839.68		300		840.40
	350		839.36		350		839.52		350		840.16
	400		839.13		400		839.28		400		839.76
	450		839.35		450		839.44		450		840.24
	495		839.32		495		839.44		495		840.16

(Continued)

Table 5 (Concluded)

Station No.	Distance from Centerline, ft Left	Right	Water Surface Elevation Above Crest	Station No.	Distance from Centerline, ft Left	Right	Water Surface Elevation Above Crest	Station No.	Distance from Centerline, ft Left	Right	Water Surface Elevation Above Crest
	Discharge: 150,000 cfs Pool Elevation: 849.2 ft				Discharge: 190,000 cfs Pool Elevation: 851.6 ft				Discharge: 284,000 cfs Pool Elevation: 856.6 ft		
20+50			844.00	20+50			846.32	20+50			848.8
		50	844.40			50	846.32			50	849.2
		100	844.55			100	846.40			100	849.6
		150	844.48			150	846.55			150	849.8
		200	844.40			200	846.88			200	850.0
		250	844.40			250	846.88			250	850.2
		300	844.32			300	846.88			300	850.4
		350	844.32			350	846.88			350	850.6
		400	844.32			400	846.88			400	850.6
		450	844.24			450	846.80			450	850.6
		495	844.32			495	846.88			495	850.7
	50		843.68		50		845.44		50		848.4
	100		843.20		100		845.12		100		847.9
	150		842.80		150		844.48		150		847.4
	200		842.80		200		844.32		200		847.3
	250		841.92		250		843.60		250		846.6
	300		841.68		300		843.44		300		845.5
	350		841.36		350		842.80		350		844.6
	400		840.72		400		841.36		400		843.4
	450		840.64		450		841.12		450		842.3
	495		840.80		495		841.12		495		841.2

Table 6

Basic Uncontrolled Spillway Rating

Data Obtained from Model

Discharge cfs	Pool Elevation ft above msl	Head on Crest ft
8,500	837.2	3.20
15,250	838.0	4.00
20,000	838.6	4.48
24,000	838.9	4.96
29,000	839.6	5.60
46,500	841.2	7.20
80,600	844.0	10.00
105,000	845.7	11.68
125,000	847.4	13.40
150,000	849.0	15.00
180,000	850.9	16.90
230,000	853.7	19.68
275,000	855.9	21.92
295,000	856.9	22.96

Table 7

1:80-Scale Model Test Conditions and Results Simulating the Proposed Rockfill Dikes for Protection of the Upstream Left Abutment of the Spillway

Spillway Design Flood: 284,000 cfs

		Velocity, fps			
Spillway Station No.	Distance from Centerline, ft	Original Proposed Rockfill Dike	Dike 1* 100'-Elliptical	Dike 2 100'-Straight	Dike 3 150'-Elliptical
20+50	425	19.5	14.5	14.5	16.0
	450	17.8	11.2	9.2	9.2
	490	11.5	11.2	6.8	6.8
20+00	425	21.5	13.0	14.5	16.0
	450	11.1	9.2	9.2	9.2
	495	11.1	9.2	6.8	6.8
19+00	425	22.5	9.2	14.5	21.0
	250	9.6	6.8	6.8	9.2
	495	9.6	6.8	14.5	6.8
	515	17.5	14.5	16.0	12.0
18+00	425	23.5	13.0	14.5	25.0
	450	11.5	11.2	9.2	9.2
	495	10.4	11.2	19.0	6.9
	510	16.4	14.5	13.0	13.0
	575	7.8	9.2	6.8	8.3

*Recommended design.

Table 8

Inflow-Outflow Hydrologic Data

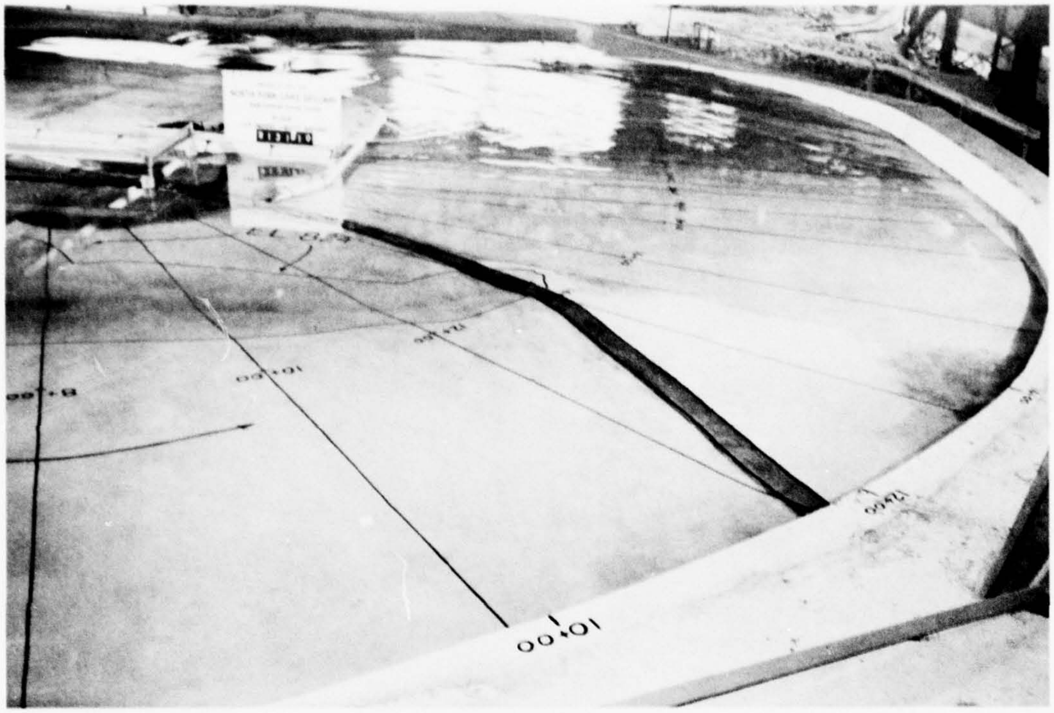
for North Fork Lake Spillway

Time hr	Inflow cfs	Outflow cfs	Storage acre-ft	Pool Elevation ft
3	400	69	130,891	834.03
6	1,500	314	131,216	834.13
9	3,500	861	131,938	834.34
12	6,250	1,615	132,932	834.65
15	7,000	2,540	134,153	835.02
18	9,650	3,750	135,764	835.50
21	12,500	5,546	137,710	836.09
24	15,150	8,994	139,664	836.67
27	18,200	12,299	141,536	837.22
30	21,350	15,546	143,376	837.78
33	30,000	21,617	146,184	838.57
36	51,900	35,886	151,898	840.19
39	132,900	88,449	169,433	844.77
42	202,500	158,093	189,079	849.44
45	300,900	249,769	213,118	854.59
48	299,500	282,687	221,340	856.24
51	140,650	190,112	197,576	851.32
54	59,650	108,417	175,357	846.23
57	28,850	62,488	161,324	842.71
60	12,000	36,302	132,032	840.23
63	4,250	21,289	145,967	838.58
66	700	12,936	141,897	837.32
69	0	8,292	139,266	836.55
72	0	6,316	137,579	836.05
75	0	4,238	136,395	835.70
78	0	3,510	135,434	835.40
81	0	2,908	134,639	835.18
84	0	2,408	133,980	834.96

(Continued)

Table 8 (Concluded)

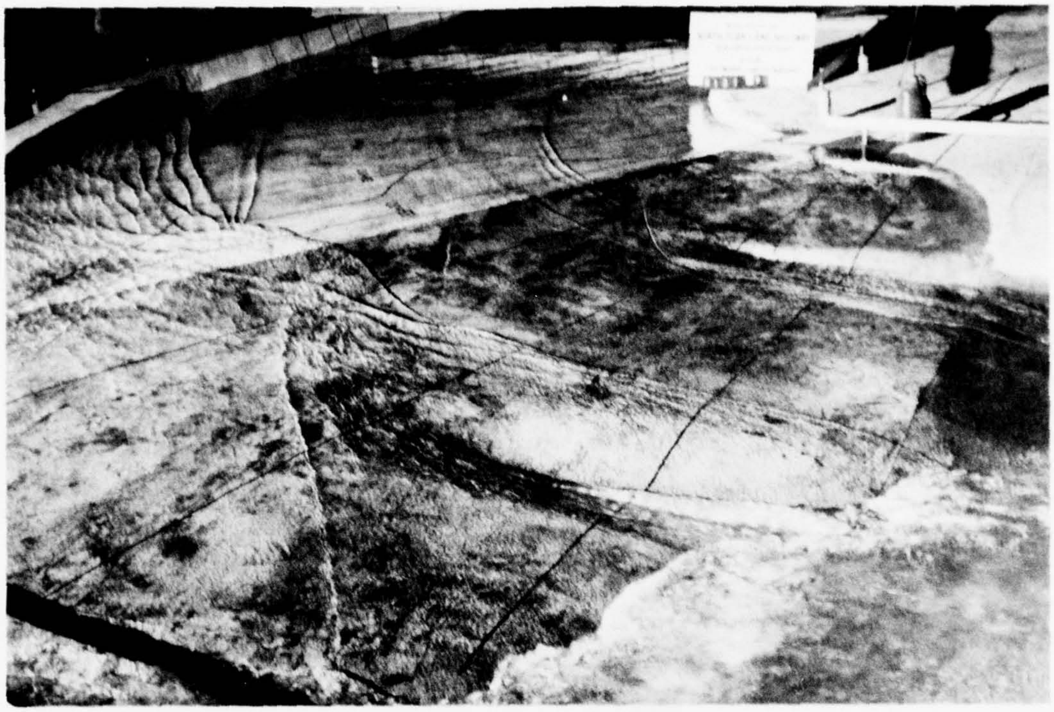
Time hr	Inflow cfs	Outflow cfs	Storage acre-ft	Pool Elevation ft
87	0	1,995	133,434	834.80
90	0	1,652	132,982	834.85
93	0	1,369	132,607	834.55
96	0	1,134	132,297	834.45
99	0	939	132,040	834.38
102	0	778	131,827	834.31
105	0	644	131,631	834.26
108	0	534	131,505	834.21
111	0	442	131,384	834.18
114	0	366	131,284	834.15
117	0	303	131,201	834.12
120	0	231	131,132	834.10



a. Discharge, 88,000 cfs; pool el, 845.0; tailwater el, 731.0

b. Discharge, 284,000 cfs; pool el, 856.6; tailwater el, 752.0

Photo 1. Flow conditions in the approach channel and at left abutment



a. Discharge, 88,000 cfs; pool el, 845.0; tailwater el, 731.0

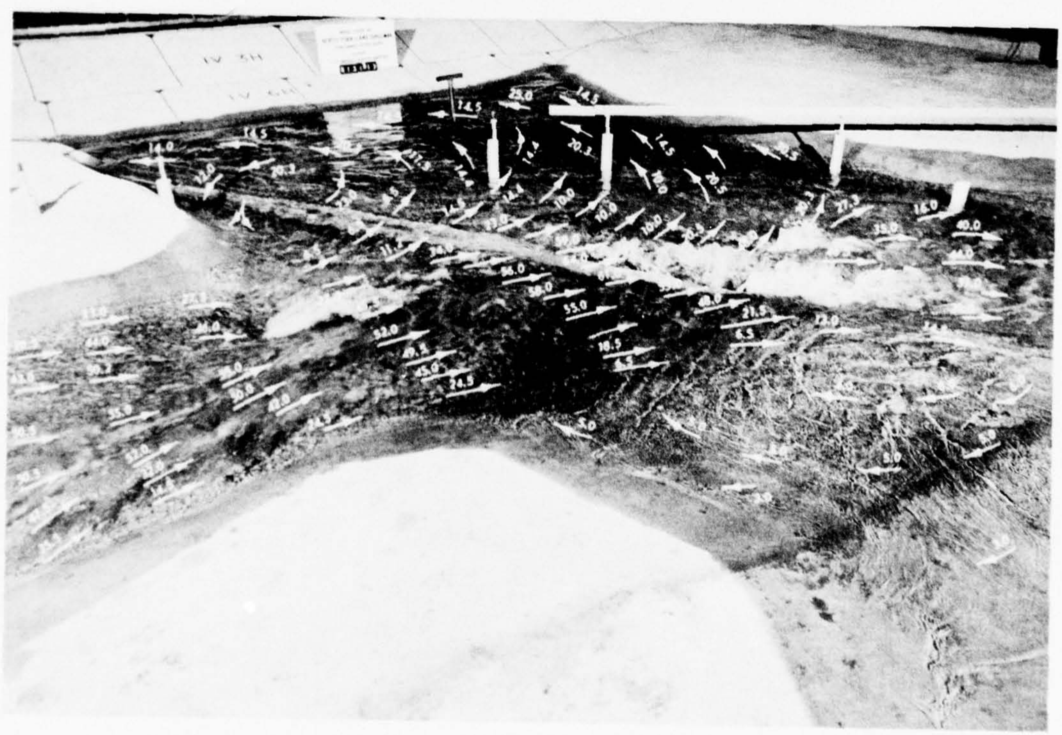
b. Discharge, 284,000 cfs; pool el, 856.6; tailwater el, 752.0

Photo 2. Flow conditions in spillway discharge channel

c. Discharge, 284,000 cfs; pool el, 856.6; tailwater el, 752.0

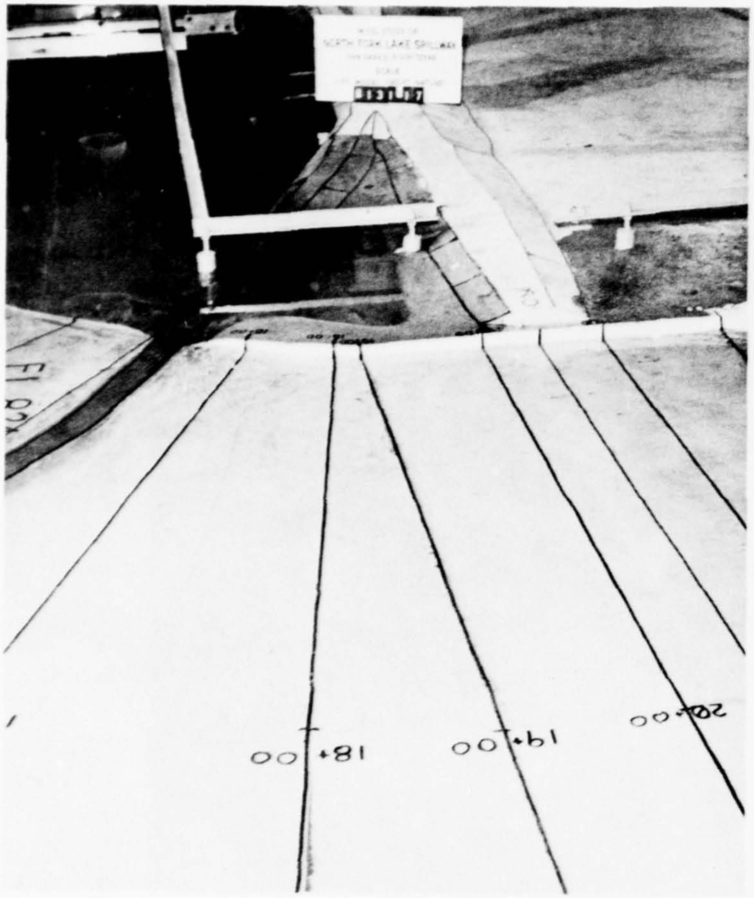
Photo 2 (sheet 2 of 2)

a. Discharge, 88,000 cfs; pool el, 845.0; tailwater el, 731.0

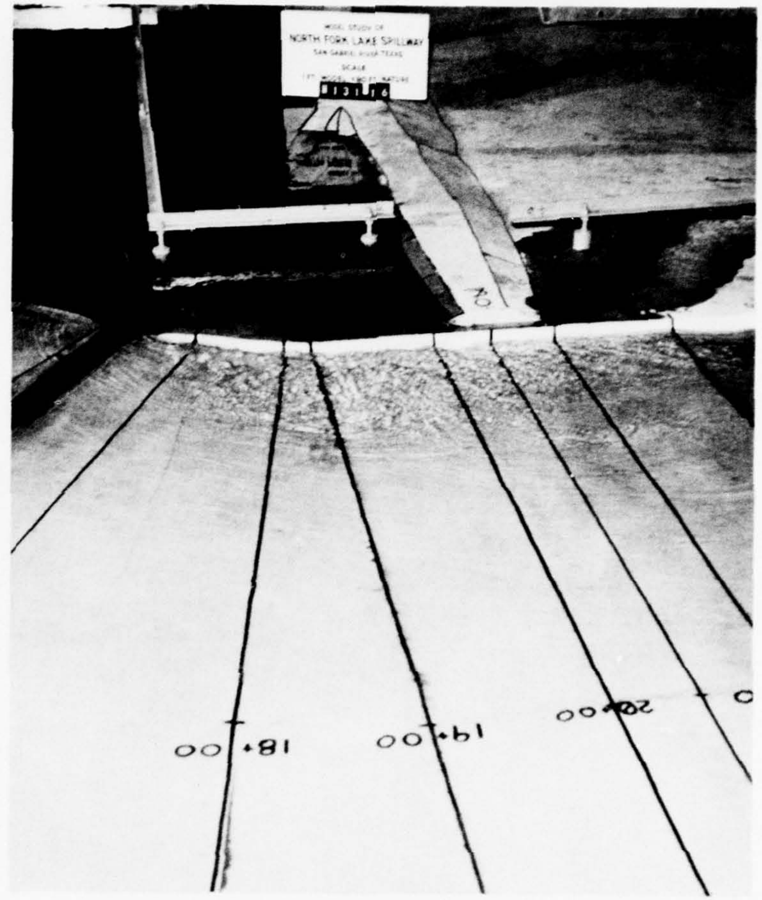


b. Discharge, 284,000 cfs; pool el, 856.6; tailwater el, 752.0

Photo 3. Flow conditions in the spillway exit channel and San Gabriel River basin, velocity and flow patterns

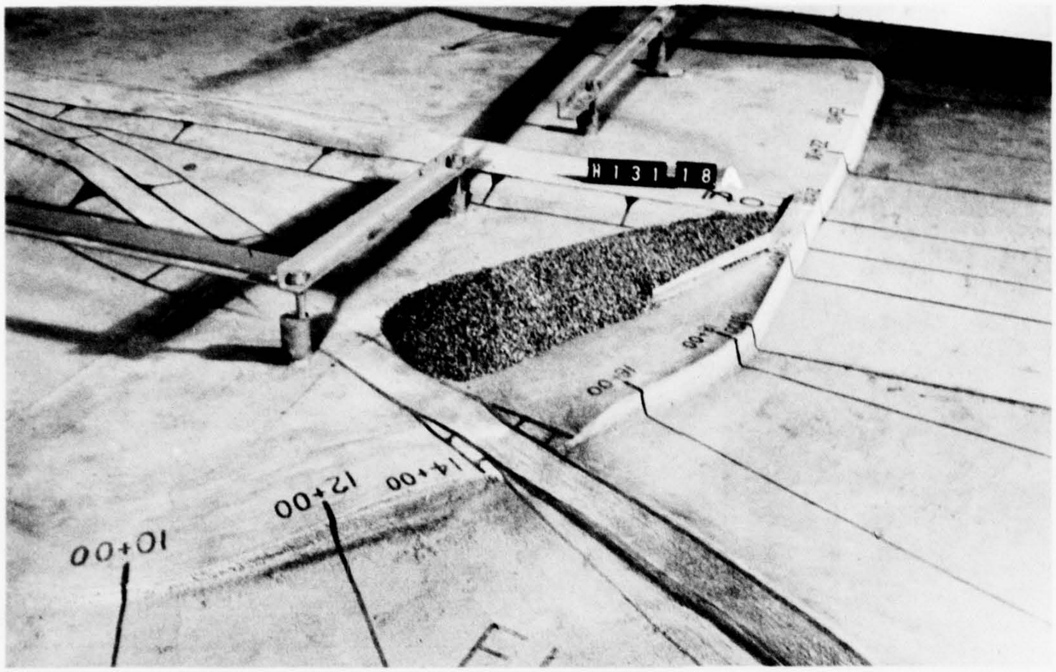


a. Discharge, 78,000 cfs; pool el, 844.2; tailwater el, 728.0

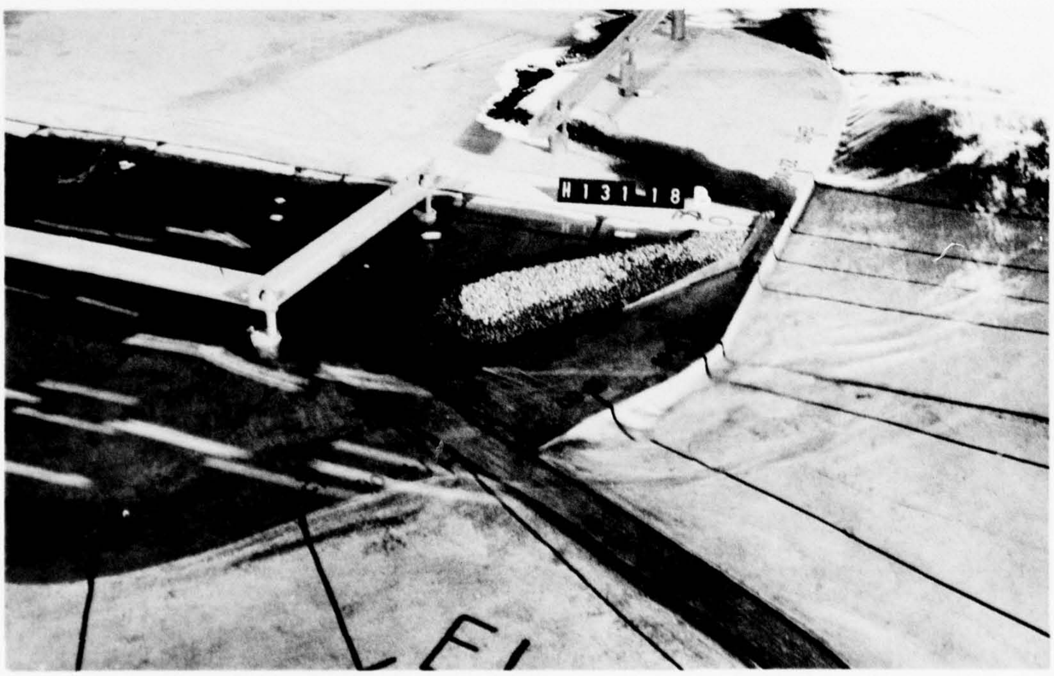


b. Discharge, 284,000 cfs; pool el, 856.6; tailwater el, 752.0

Photo 4. Flow conditions at the left abutment of the spillway



a. Dry-bed view



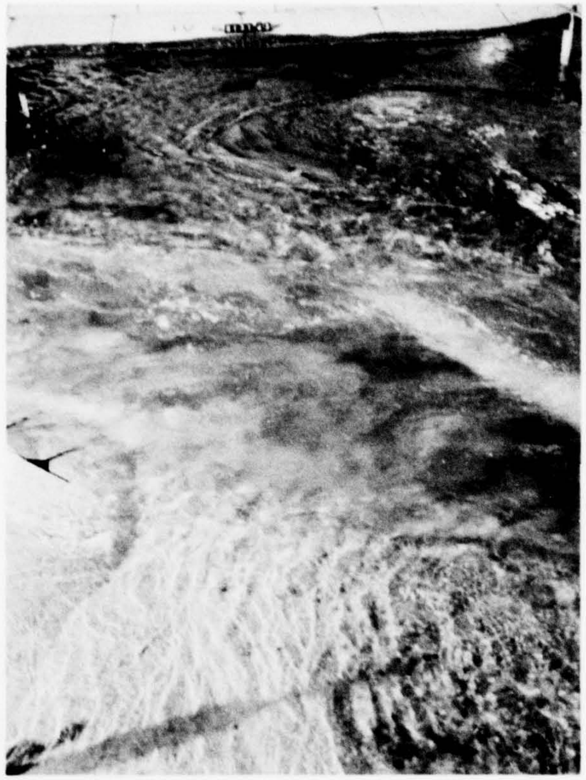
b. Discharge, 284,000 cfs; pool el, 856.6; tailwater el, 752.0

Photo 5. Proposed rockfill dike (original) at left abutment of spillway

a. Discharge, 78,000 cfs; pool el, 844.2; tailwater el, 728.0

b. Discharge, 284,000 cfs; pool el, 856.6; tailwater el, 752.0

Photo 6. Flow conditions in the exit channel and San Gabriel River basin



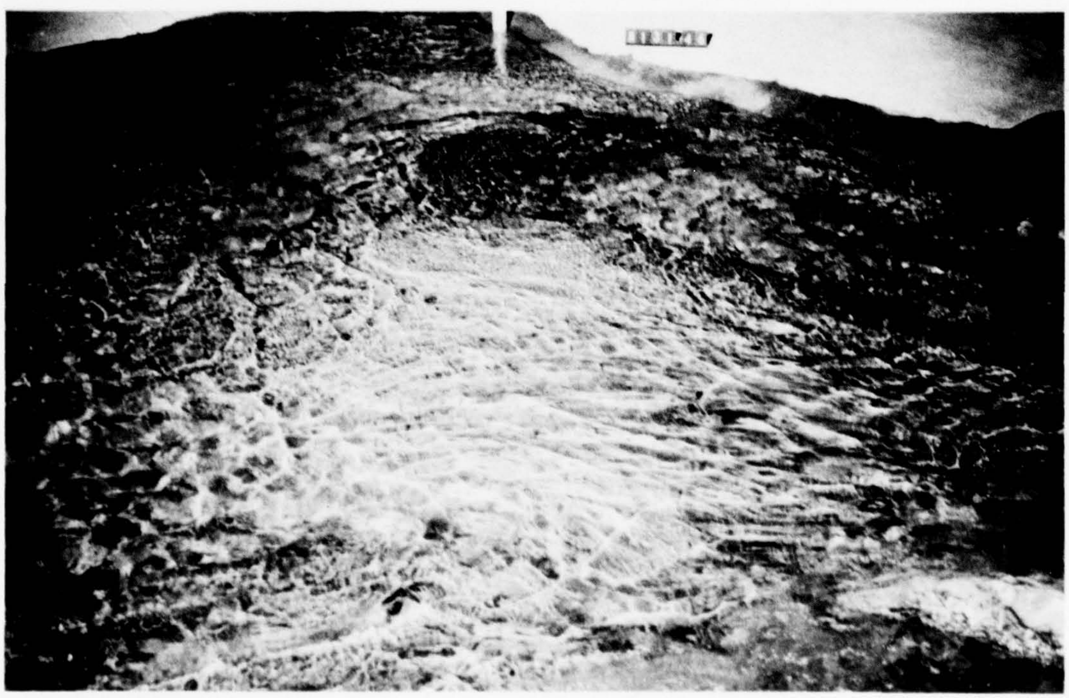


Photo 7. Flow characteristics for spillway design flood. Discharge, 284,000 cfs; pool el, 856.5; tailwater el, 752.0

Exit channel

San Gabriel River basin

Photo 8. San Gabriel River basin scour resulting from 120-hour hydrograph; peak discharge of 284,000 cfs (8-hr model test duration)

Photo 9. Exit channel and San Gabriel River basin scour with rockfill dikes (type 1 design), rock size d_{50} = 40 in., resulting from 120-hour hydrograph, peak discharge of 284,000 cfs (8-hr model test duration)

a. Type 2 design rockfill dikes

b. Type 3 design rockfill dikes

Photo 10. Exit channel and San Gabriel River basin scour resulting from 120-hour hydrograph, peak discharge of 284,000 cfs (8-hr model test duration)

Photo 11. Exit channel and San Gabriel River basin scour with recommended rockfill dikes (type 4 design), rock size d_{50} = 25 in., resulting from 120-hour hydrograph, peak discharge of 284,000 cfs (8-hr model test duration) (sheet 1 of 3)

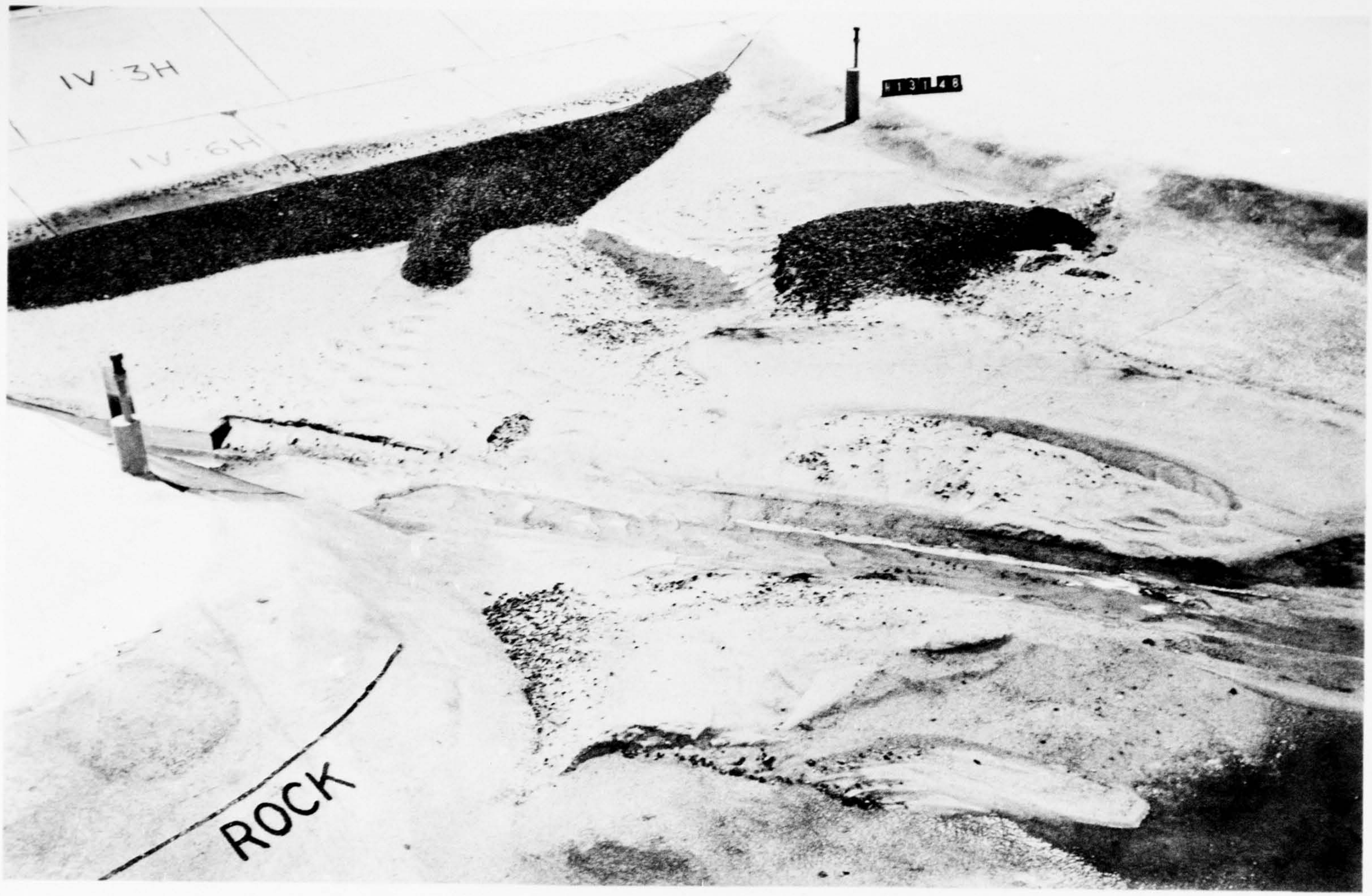
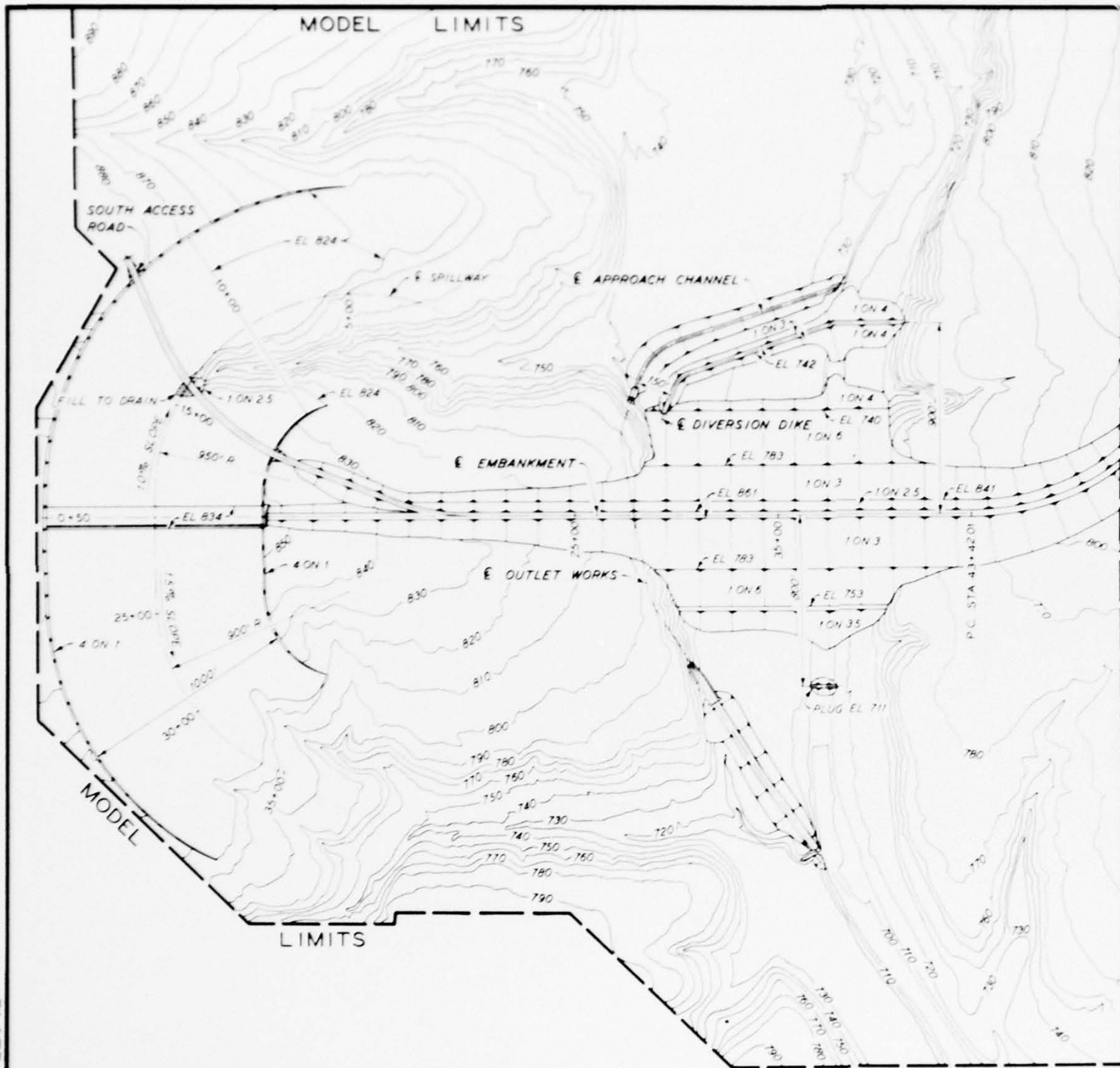


Photo 11 (sheet 2 of 3)

Photo 11 (sheet 3 of 3)

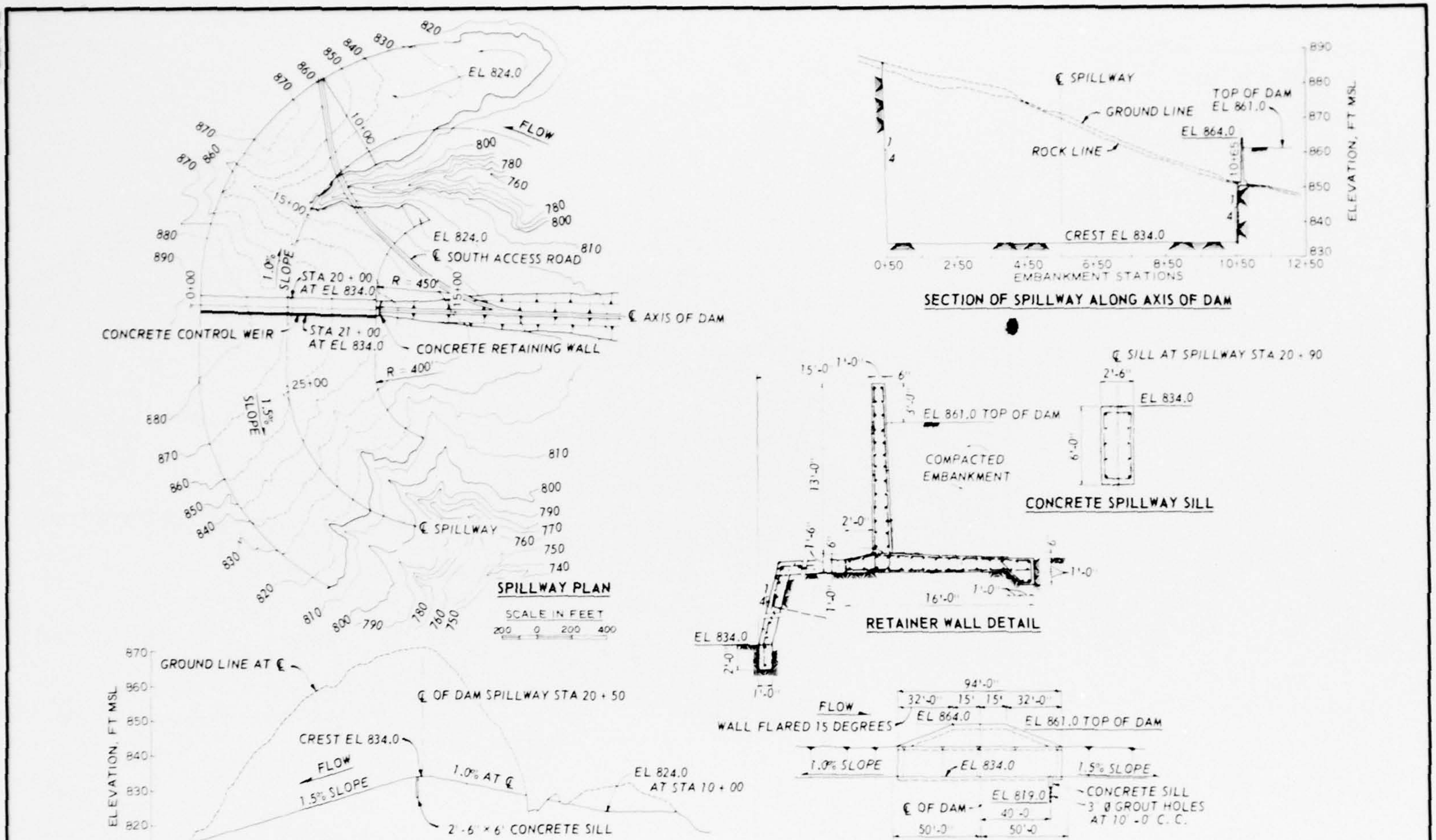


GENERAL PLAN AND
MODEL LIMITS

SCALE IN FEET

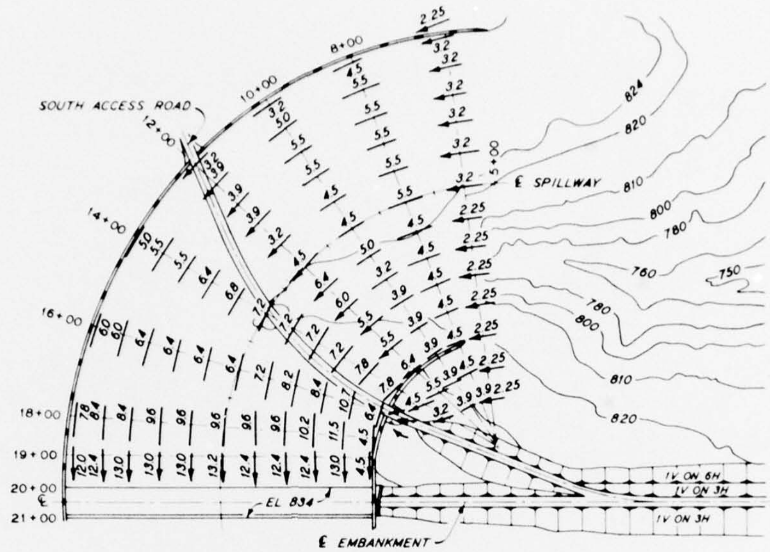
500 0 500 1000

PLATE 2



SPILLWAY

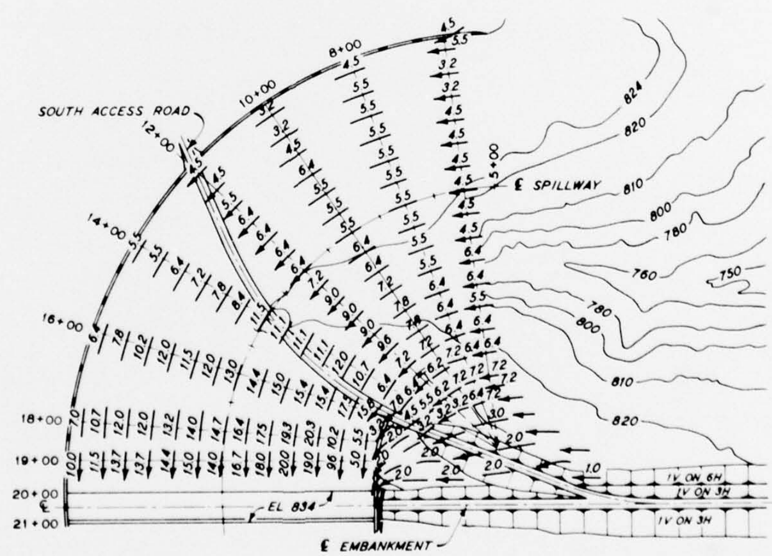
PLAN, PROFILE, AND SECTIONS



Q = 88,000

TEST CONDITIONS

DISCHARGE .... 88,000 CFS
POOL ELEVATION ..... 845.0 FT



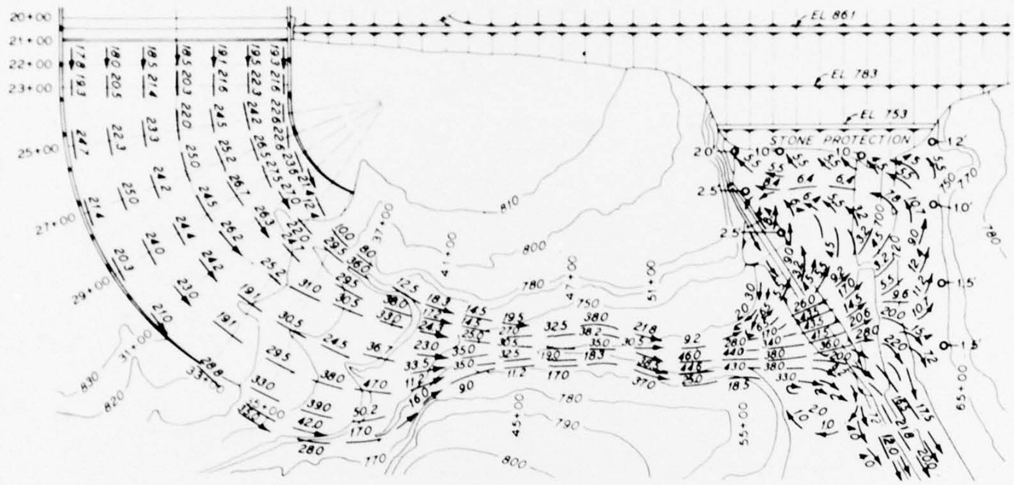
Q = 284,000

TEST CONDITIONS

DISCHARGE .... 284,000 CFS
POOL ELEVATION ..... 856.6 FT

NOTE: ALL VELOCITIES ARE IN
PROTOTYPE FEET PER SECOND

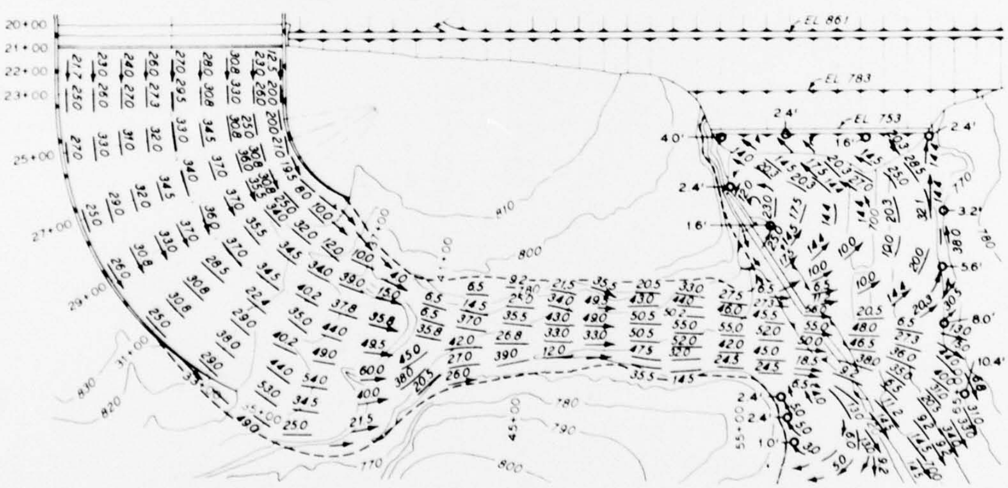
VELOCITY AND FLOW PATTERNS
IN SPILLWAY APPROACH CHANNEL



Q = 88,000

TEST CONDITIONS

DISCHARGE	88,000 CFS
POOL ELEVATION	845.0 FT
TAILWATER EL	731.0 FT



Q = 284,000

TEST CONDITIONS

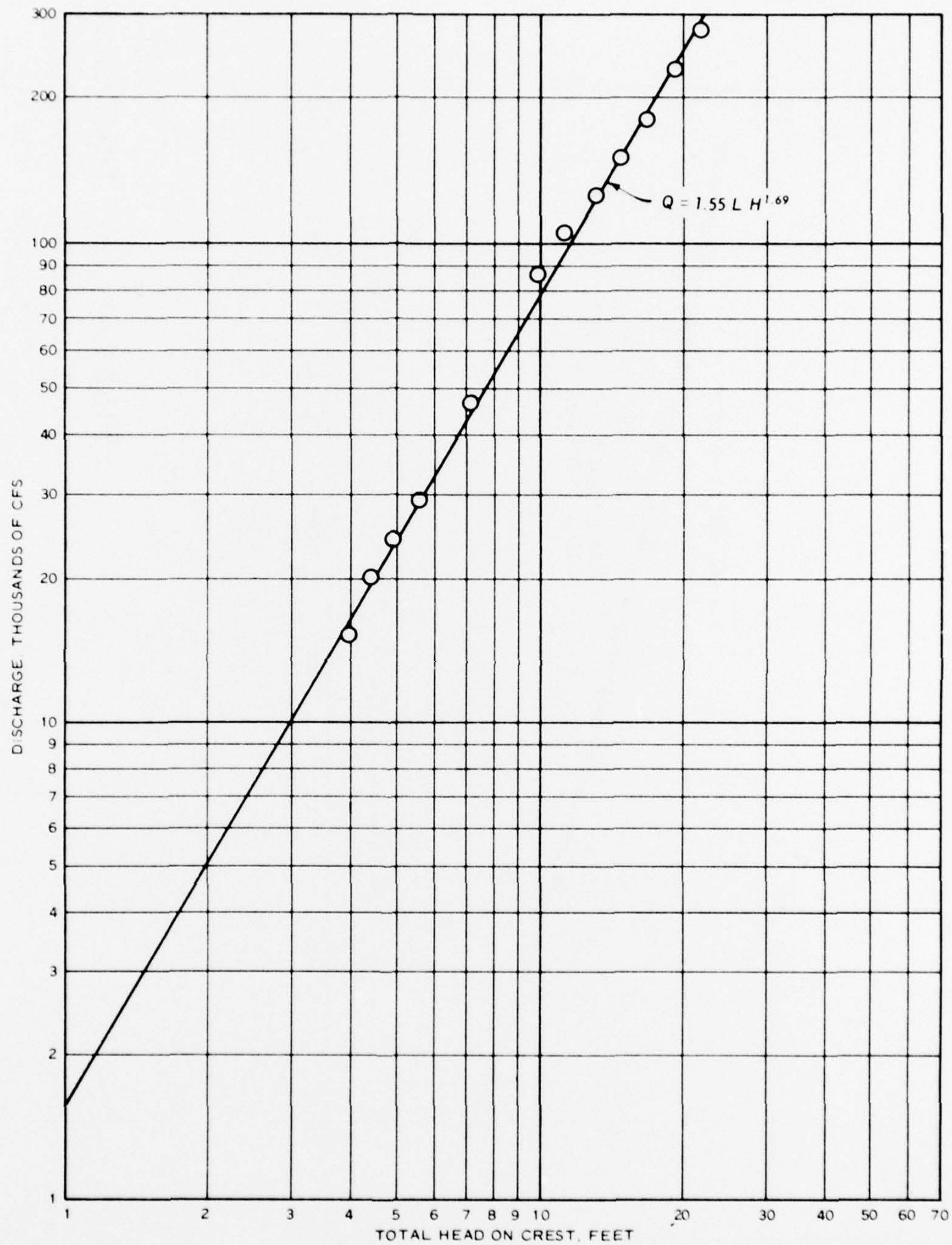
DISCHARGE	284,000 CFS
POOL ELEVATION	856.6 FT
TAILWATER EL	752.0 FT

O = WAVE HEIGHT

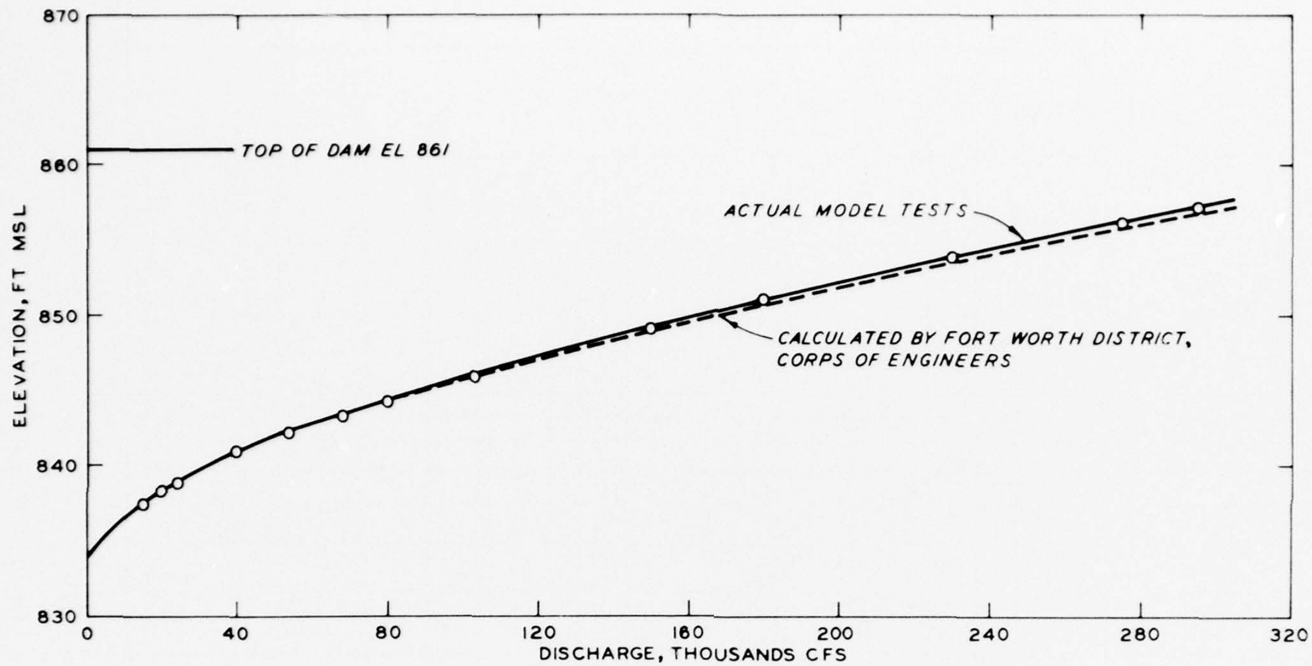
NOTE ALL VELOCITIES ARE IN PROTOTYPE FEET PER SECOND

VELOCITY AND FLOW PATTERNS IN SPILLWAY DISCHARGE AND EXIT CHANNEL

PLATE 4



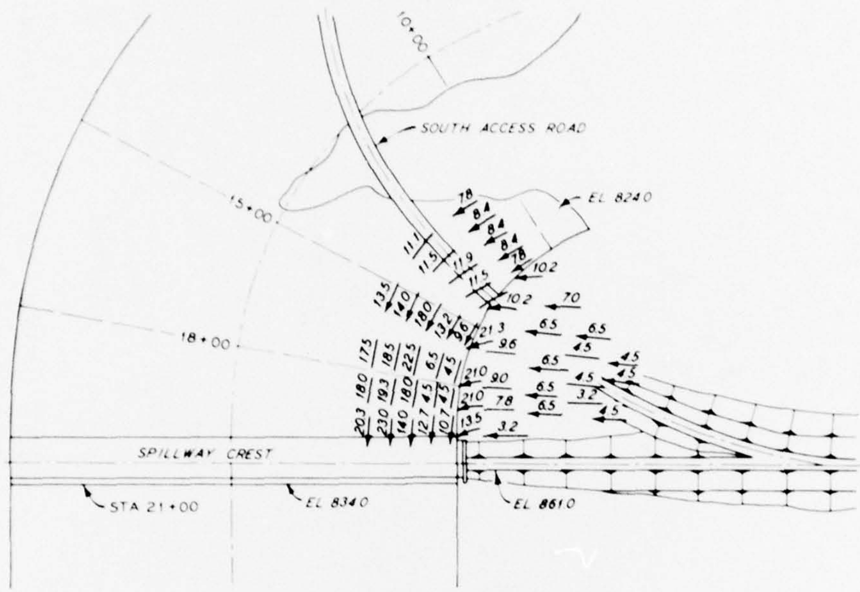
HEAD-DISCHARGE RELATIONSHIP FOR UNCONTROLLED FLOW



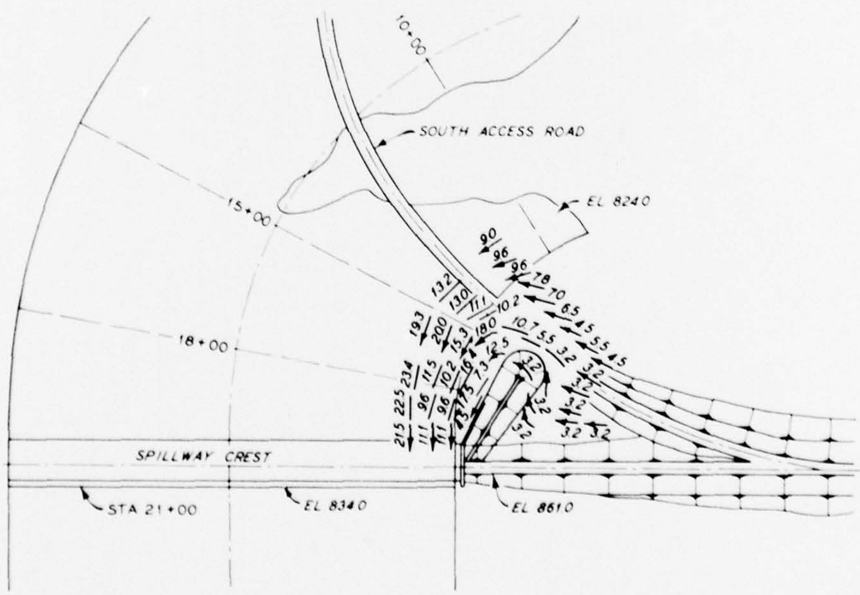
SPILLWAY RATING CURVE

NORTH FORK SPILLWAY

17 OCTOBER 1974



ORIGINAL DESIGN

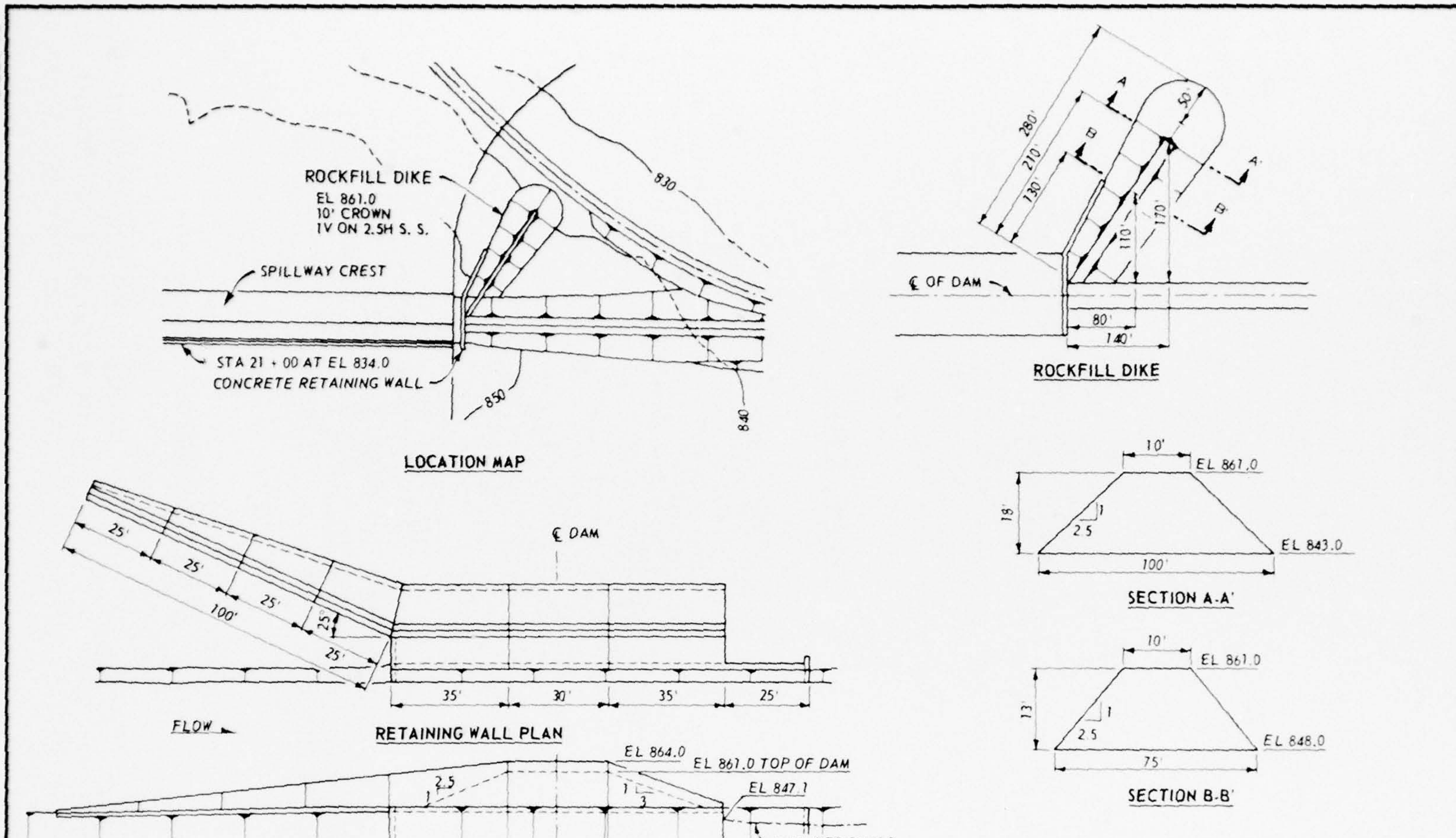


PROPOSED DESIGN

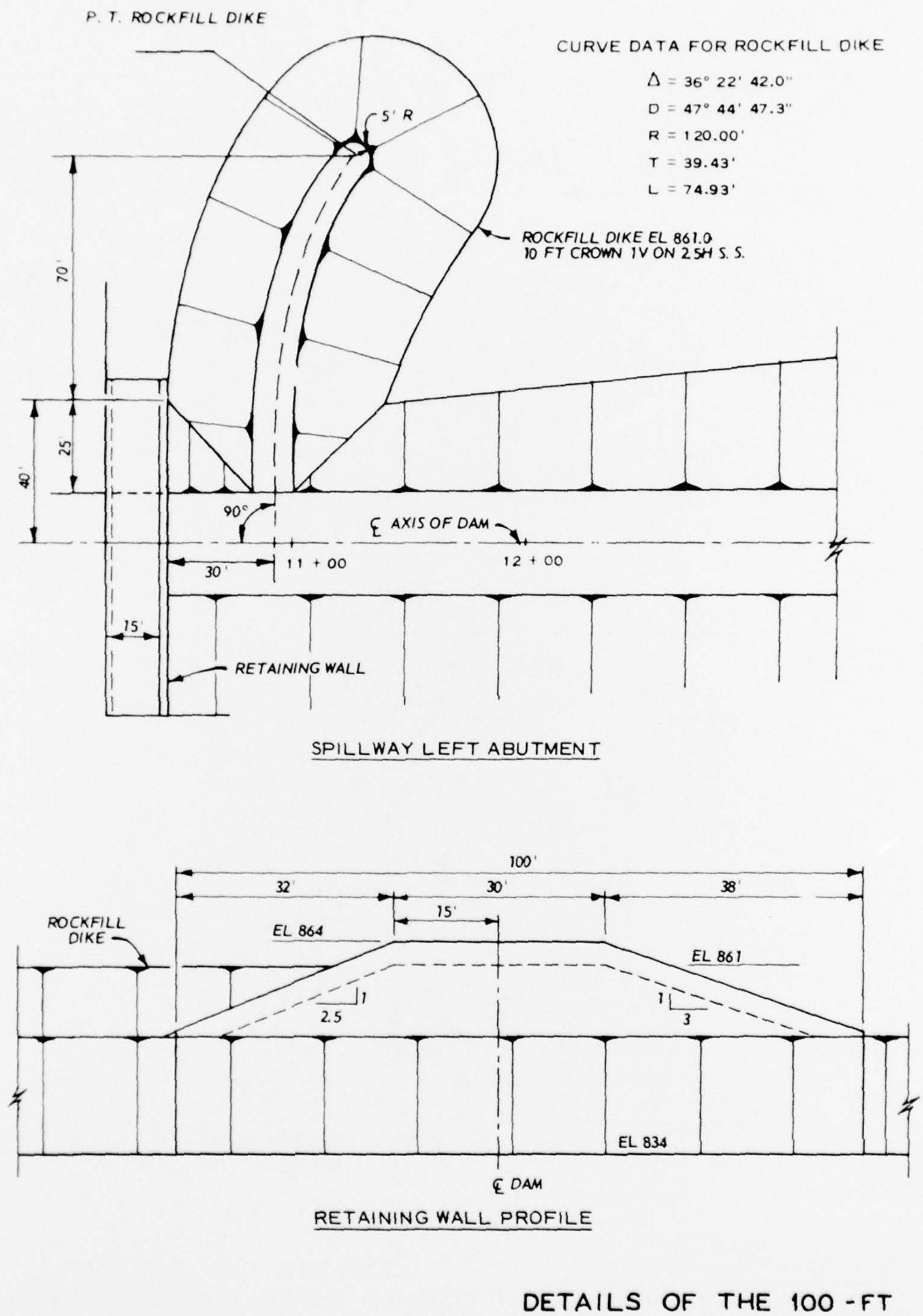
TEST CONDITIONS

DISCHARGE 284,000 CFS
POOL ELEVATION 8566 FT

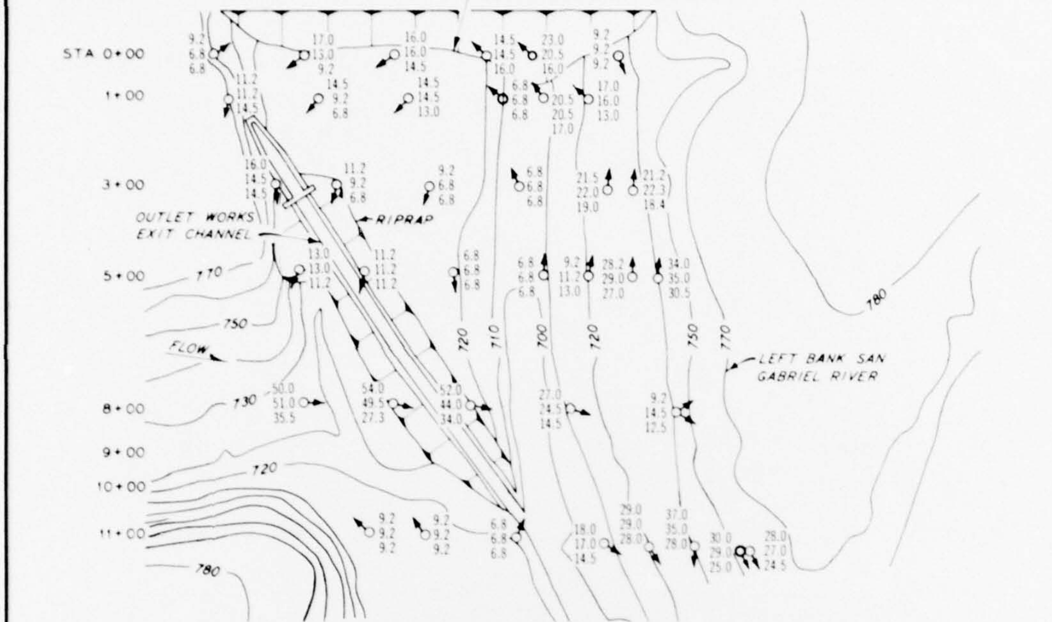
VELOCITIES AND CURRENTS IN SPILLWAY APPROACH
ORIGINAL AND PROPOSED DESIGN



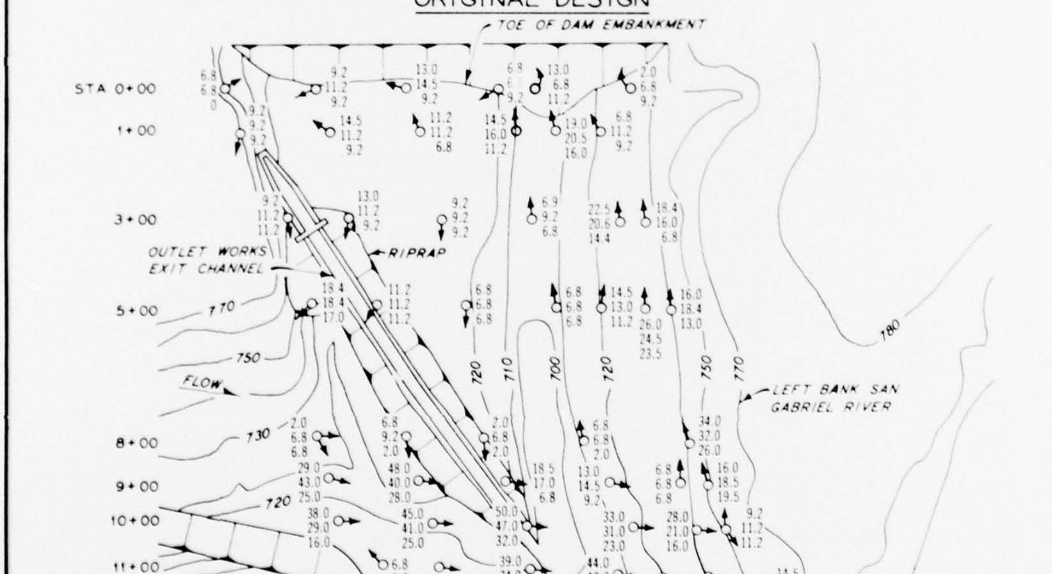
DETAILS OF LEFT ABUTMENT
PROPOSED ROCKFILL DIKE
TYPE 1 (ORIGINAL) DESIGN



DETAILS OF THE 100-FT ELLIPTICAL ROCKFILL DIKE AND THE RETAINING WALL (RECOMMENDED DESIGN)



ORIGINAL DESIGN



MODIFIED RIGHT BLUFF

LEGEND

DIRECTION OF SURFACE CURRENTS AND MAGNITUDE OF VELOCITIES - SURFACE, MIDDLE, AND BOTTOM

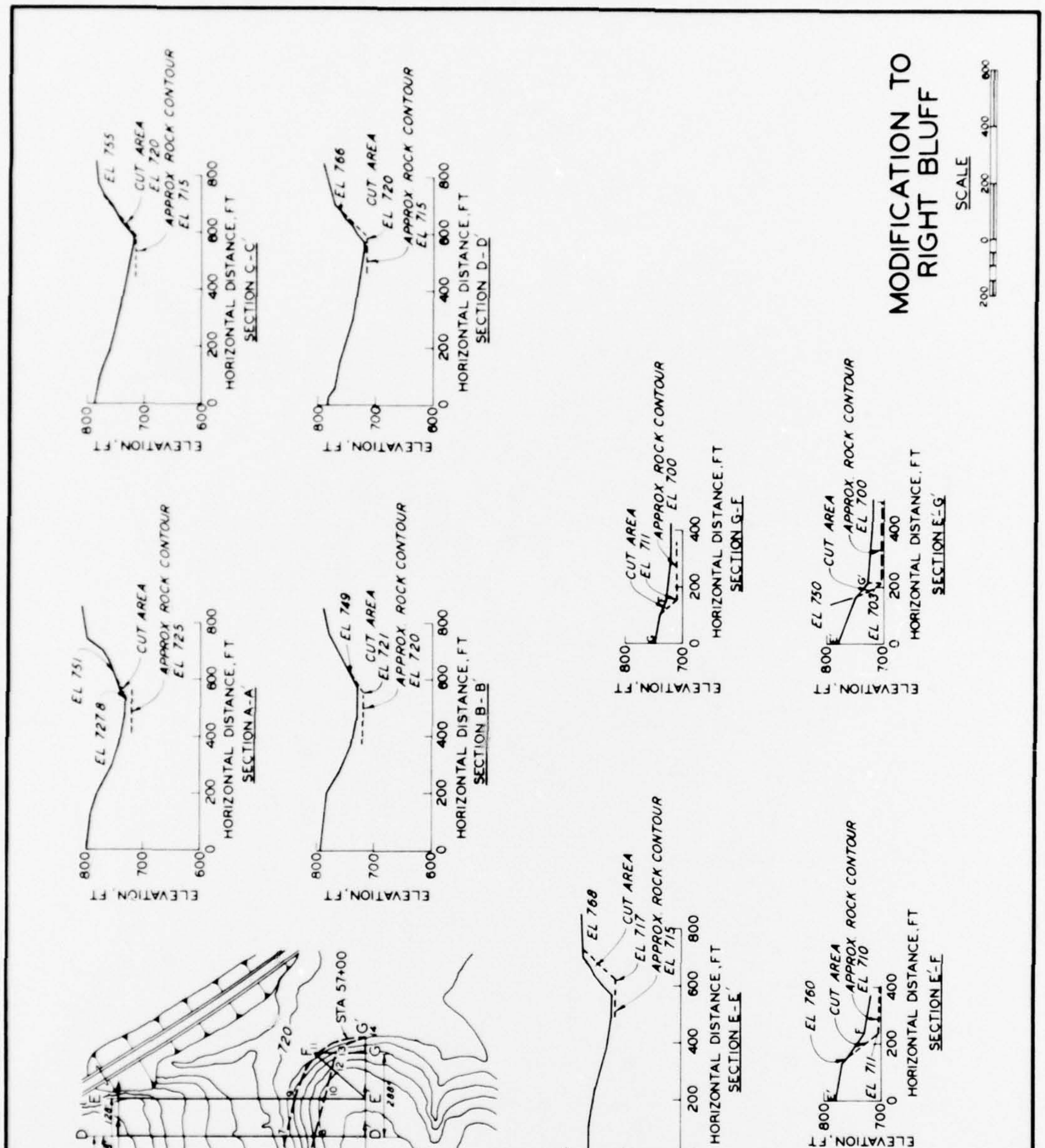
TEST CONDITIONS

DISCHARGE .... 284,000 CFS
POOL ELEVATION .... 856.6 FT
TAILWATER EL .... 752.0 FT

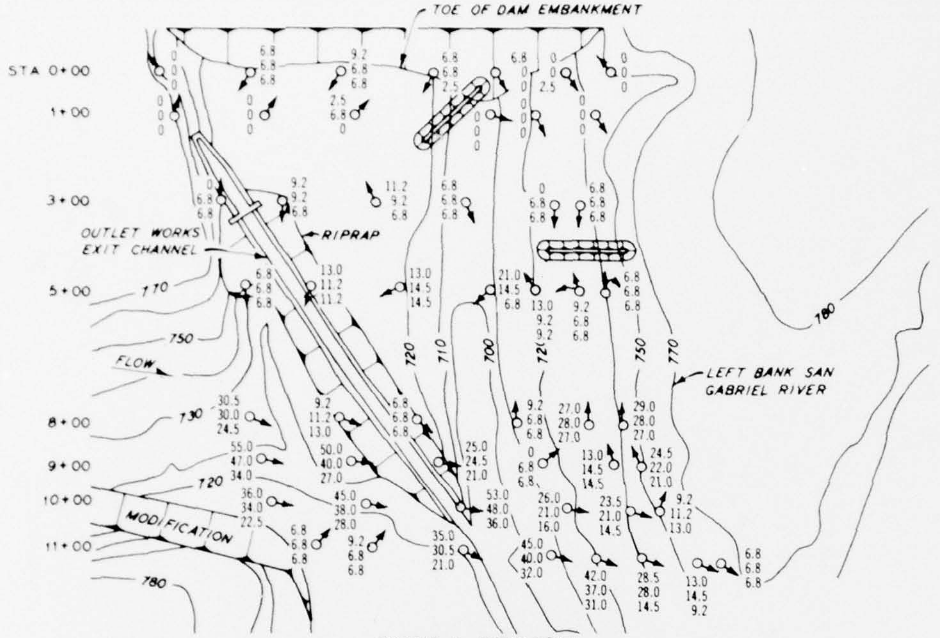
NOTE: ALL VELOCITIES ARE IN PROTOTYPE FEET PER SECOND

VELOCITIES AND CURRENT PATTERNS IN EXIT CHANNEL AND SAN GABRIEL RIVER BASIN

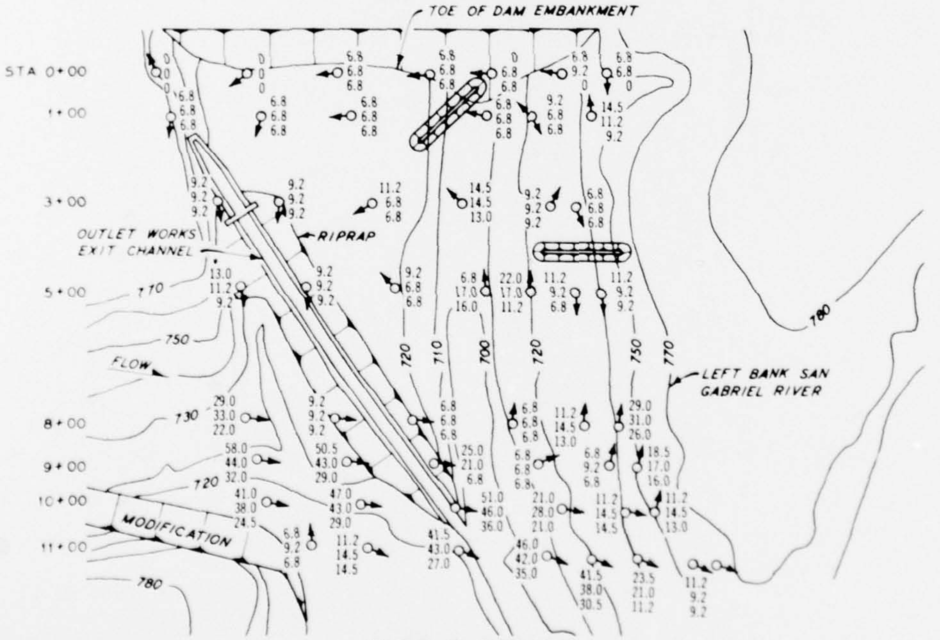
ORIGINAL DESIGN AND MODIFIED RIGHT BLUFF



MODIFICATION TO RIGHT BLUFF
SCALE
200 0 200 400 800
LEFT
RIGHT
FLOW
STA 48+00
STA 57+00
790
780
770
760
750
740
730
720
A A'
B B'
C C'
D D'
E E'
F
G G'
ELEVATION, FT
HORIZONTAL DISTANCE, FT
SECTION A-A'
EL 727.8
EL 751
CUT AREA
APPROX ROCK CONTOUR
EL 725
SECTION B-B'
EL 749
EL 721
EL 720
SECTION C-C'
EL 755
EL 720
EL 715
SECTION D-D'
EL 766
SECTION E-E'
EL 768
EL 717
SECTION G-F
EL 711
EL 700
SECTION E'-F
EL 760
EL 710
SECTION E'-G'
EL 750
EL 703



TYPE 1 DESIGN



TYPE 2 DESIGN

LEGEND

DIRECTION OF SURFACE CURRENTS AND MAGNITUDE OF VELOCITIES - SURFACE, MIDDLE, AND BOTTOM

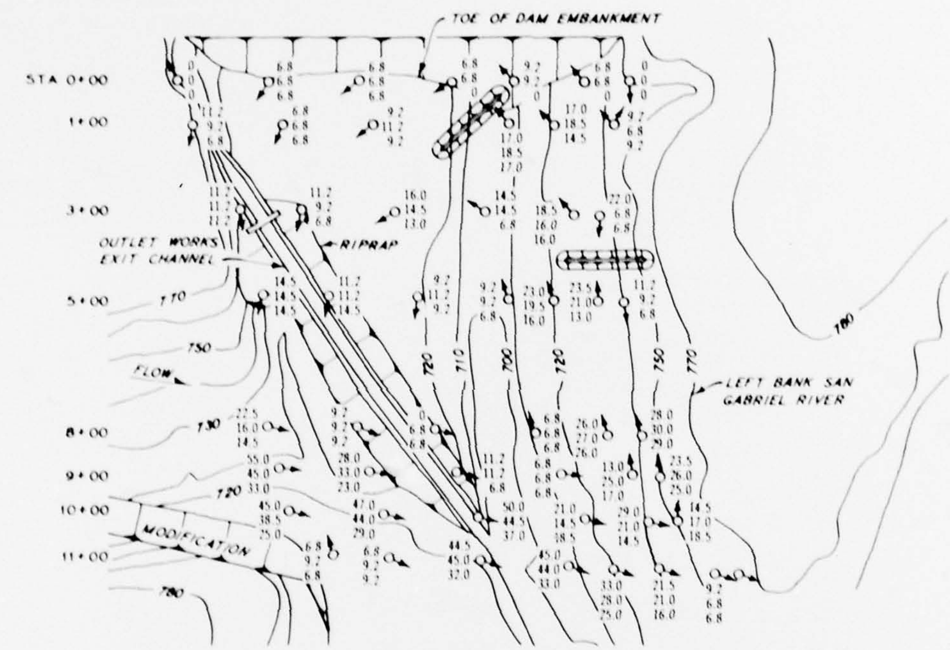
TEST CONDITIONS

DISCHARGE	284,000 CFS
POOL ELEVATION	856.6 FT
TAILWATER EL	752.0 FT

NOTE ALL VELOCITIES ARE IN PROTOTYPE FEET PER SECOND.

VELOCITIES AND CURRENT PATTERNS IN EXIT CHANNEL AND SAN GABRIEL RIVER BASIN

ROCKFILL DIKE
TYPES 1 AND 2



TYPE 4 DESIGN

LEGEND

DIRECTION OF SURFACE CURRENTS AND MAGNITUDE OF VELOCITIES – SURFACE, MIDDLE, AND BOTTOM

TEST CONDITIONS

DISCHARGE	284,000 CFS
POOL ELEVATION	856.6 FT
TAILWATER EL	752.0 FT

NOTE: ALL VELOCITIES ARE IN PROTOTYPE FEET PER SECOND

VELOCITIES AND CURRENT PATTERNS IN EXIT CHANNEL AND SAN GABRIEL RIVER BASIN

ROCKFILL DIKE
TYPE 4
(RECOMMENDED DESIGN)

In accordance with ER 70-2-3, paragraph 6c(1)(b), dated 15 February 1973, a facsimile catalog card in Library of Congress format is reproduced below.

Rothwell, Edward D
North Fork Lake Spillway, San Gabriel River, Texas; hydraulic model investigation, by Edward D. Rothwell. Vicksburg, U. S. Army Engineer Waterways Experiment Station, 1976.
1 v. (various pagings) illus. 27 cm. (U. S. Waterways Experiment Station. Technical report H-76-10)
Prepared for U. S. Army Engineer District, Fort Worth, Fort Worth, Texas.

1. Hydraulic models. 2. North Fork Lake Dam. 3. San Gabriel River. 4. Spillways. I. U. S. Army Engineer District, Fort Worth. (Series: U. S. Waterways Experiment Station, Vicksburg, Miss. Technical report H-76-10)
TA7.W34 no.H-76-10